

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Patent Application of: )  
Nobuharu OHSAWA et al. )  
Application No.: 10/590,703 ) Examiner: Marie R. Yamnitzky  
Filed: August 25, 2006 ) Group Art Unit: 1794  
For: LIGHT EMITTING ELEMENT AND )  
LIGHT EMITTING DEVICE )  
)

VERIFICATION OF TRANSLATION

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Dear Sir:

I, Hiromi SHAKADO, C/O Semiconductor Energy Laboratory Co., Ltd. 398, Hase, Atsugi-shi, Kanagawa-ken 243-0036 Japan, a translator, herewith declare:

that I am well acquainted with both the Japanese and English Languages;

that I am the translator of the attached English translation of the Japanese Patent Application No. 2004-231742 filed on August 6, 2004; and

that to the best of my knowledge and belief the following is a true and correct English translation of the Japanese Patent Application No. 2004-231742 filed on August 6, 2004.

I further declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

Date: this 8th day of January 2010

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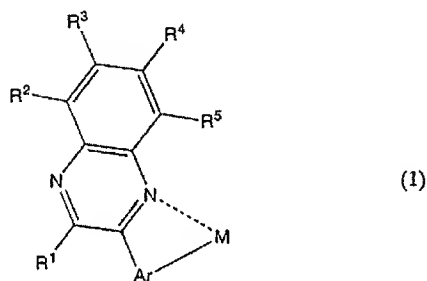
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[Document Name] Scope of Claims

[Claim 1]

- 5 A light-emitting element characterized by including a light-emitting layer which includes an organometallic complex including a partial structure represented by the general formula (1) and a compound that has a larger energy gap than the organometallic complex between a pair of electrodes.

[Chemical Formula 1]

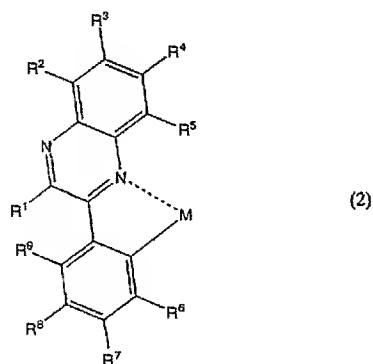


- 10 (In the formula,  $R^1 \sim R^5$  are any of hydrogen, a halogen element, an acyl group, an alkyl group, an alkoxyl group, an aryl group, a cyano group, or a heterocyclic group, Ar is an aryl group having an electron-withdrawing substituent or a heterocyclic group having an electron-withdrawing substituent, and M is an element of Group 9 or an element of Group 10.)

[Claim 2]

- 15 A light-emitting element characterized by including a light-emitting layer which includes an organometallic complex including a partial structure represented by the general formula (2) and a compound that has a larger energy gap than the organometallic complex between a pair of electrodes.

[Chemical Formula 2]

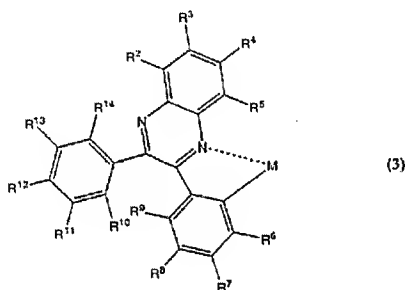


(In the formula,  $R^1 \sim R^9$  are any of hydrogen, a halogen element, an acyl group, an alkyl group, an alkoxyl group, an aryl group, a cyano group, or a heterocyclic group, at least one of  $R^6$  to  $R^9$  is an electron-withdrawing substituent, and M is an element of Group 9 or an element of Group 10.)

5 [Claim 3]

A light-emitting element characterized by including a light-emitting layer which includes an organometallic complex including a partial structure represented by the general formula (3) and a compound that has a larger energy gap than the organometallic complex between a pair of electrodes.

10 [Chemical Formula 3]

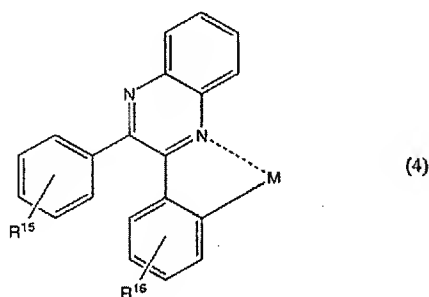


(In the formula,  $R^2 \sim R^{14}$  are any of hydrogen, a halogen element, an acyl group, an alkyl group, an alkoxyl group, an aryl group, a cyano group, or a heterocyclic group, and M is an element of Group 9 or an element of Group 10.)

15 [Claim 4]

A light-emitting element characterized by including a light-emitting layer which includes an organometallic complex including a partial structure represented by the general formula (4) and a compound that has a larger energy gap than the organometallic complex between a pair of electrodes.

20 [Chemical Formula 4]

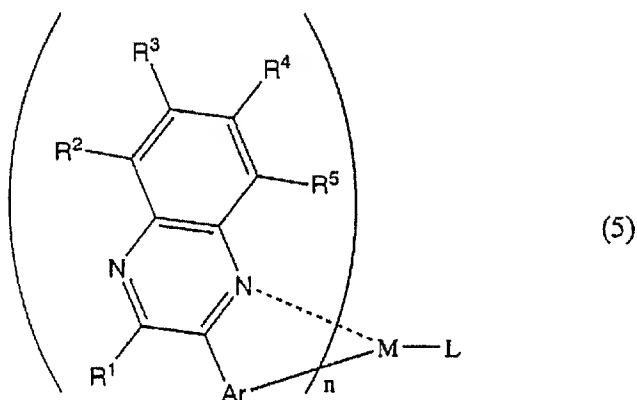


(In the formula,  $R^{15}$  and  $R^{16}$  are any of hydrogen, a halogen element, an acyl group, an alkyl group, an alkoxyl group, an aryl group, a cyano group, or a heterocyclic group, and M is an element of Group 9 or an element of Group 10.)

[Claim 5]

- 5 A light-emitting element characterized by including a light-emitting layer which includes an organometallic complex represented by the general formula (5) and a compound that has a larger energy gap than the organometallic complex between a pair of electrodes.

[Chemical Formula 5]



10

(In the formula,  $R^1 \sim R^5$  are any of hydrogen, a halogen element, an acyl group, an alkyl group, an alkoxyl group, an aryl group, a cyano group, or a heterocyclic group, Ar is an aryl group having an electron-withdrawing substituent or a heterocyclic group having an electron-withdrawing substituent, M is an element of Group 9 or an element of Group 10,  $n = 2$  when the M is the element of Group 9 while  $n = 1$  when the M is the element of Group 10, and L is a monoanionic ligand.)

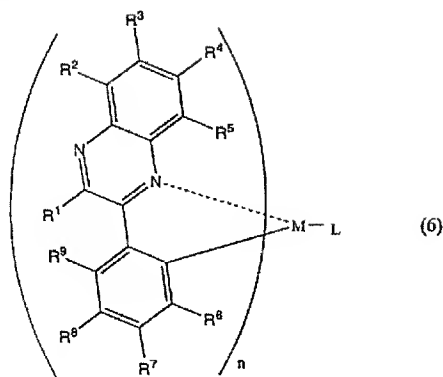
15

[Claim 6]

A light-emitting element characterized by including a light-emitting layer which includes an organometallic complex represented by the general formula (6) and a compound that has a larger energy gap than the organometallic complex between a pair of electrodes.

20

[Chemical Formula 6]

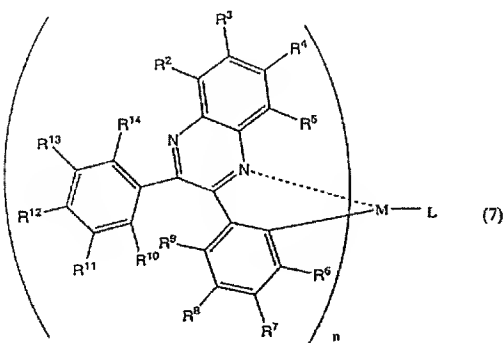


- (In the formula,  $R^1 \sim R^9$  are any of hydrogen, a halogen element, an acyl group, an alkyl group, an alkoxyl group, an aryl group, a cyano group, or a heterocyclic group.
- 5 Note that at least one of  $R^6 \sim R^9$  is an electron-withdrawing substituent. M is an element of Group 9 or an element of Group 10,  $n = 2$  when the M is the element of Group 9 while  $n = 1$  when the M is the element of Group 10, and L is an anionic ligand.)

[Claim 7]

- 10 A light-emitting element characterized by including a light-emitting layer which includes an organometallic complex represented by the general formula (7) and a compound that has a larger energy gap than the organometallic complex between a pair of electrodes.

[Chemical Formula 7]



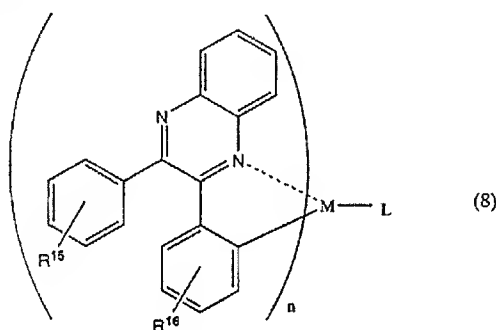
- 15 (In the formula,  $R^2 \sim R^{14}$  are any of hydrogen, a halogen element, an acyl group, an alkyl group, an alkoxyl group, an aryl group, a cyano group, or a heterocyclic group, M is an element of Group 9 or an element of Group 10,  $n = 2$  when the M is the element

of Group 9 while  $n = 1$  when the M is the element of Group 10, and L is an anionic ligand.)

[Claim 8]

- 5 A light-emitting element characterized by including a light-emitting layer which includes an organometallic complex represented by the general formula (8) and a compound that has a larger energy gap than the organometallic complex between a pair of electrodes.

[Chemical Formula 8]



- 10 (In the formula,  $R^{15}$  and  $R^{16}$  are any of hydrogen, a halogen element, an acyl group, an alkyl group, an alkoxyl group, an aryl group, a cyano group, or a heterocyclic group, M is an element of Group 9 or an element of Group 10,  $n = 2$  when the M is the element of Group 9 while  $n = 1$  when the M is the element of Group 10, and L is an anionic ligand.)

- 15 [Claim 9]

The light-emitting element according to any one of claims 1 ~ 8, characterized in that the compound that has the larger energy gap than the organometallic complex is 4,4'-bis[N-(1-naphthyl)-N-phenylamino]biphenyl or tris(8-quinolinolato)aluminum.

[Claim 10]

- 20 The light-emitting element according to any one of claims 5 ~ 8, characterized in that the anionic ligand is a monoanionic ligand having a  $\beta$ -diketone structure, a monoanionic bidentate ligand having a carboxyl group, or a monoanionic bidentate ligand having a phenolic hydroxyl group.

[Claim 11]

- 25 The light-emitting element according to any one of claims 1 ~ 8, characterized



in that any of a first compound that has a larger energy gap than the organometallic complex and has an electron mobility of  $10^{-6}$  cm<sup>2</sup>/Vs or more or a second compound that has a larger energy gap than the organometallic complex and has a hole mobility of  $10^{-6}$  cm<sup>2</sup>/Vs or more is included together with the organometallic complex.

5 [Claim 12]

The light-emitting element according to any one of claims 1 ~ 8, characterized in that a first compound that has a larger energy gap than the organometallic complex and has an electron mobility of  $10^{-6}$  cm<sup>2</sup>/Vs or more and a second compound that has a larger energy gap than the organometallic complex and has a hole mobility of  $10^{-6}$  cm<sup>2</sup>/Vs or more are included together with the organometallic complex.

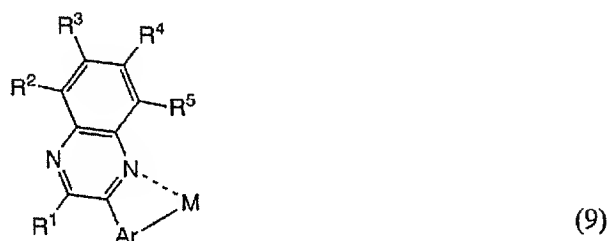
[Claim 13]

The light-emitting element according to claim 11 or 12, characterized in that the first compound is a metal complex and the second compound is an aromatic amine compound.

15 [Claim 14]

A light-emitting element characterized by including a light-emitting layer which includes an organometallic complex including a partial structure represented by the general formula (9) and a compound that has a larger ionization potential and a smaller electron affinity than the organometallic complex between a pair of electrodes.

20 [Chemical Formula 9]

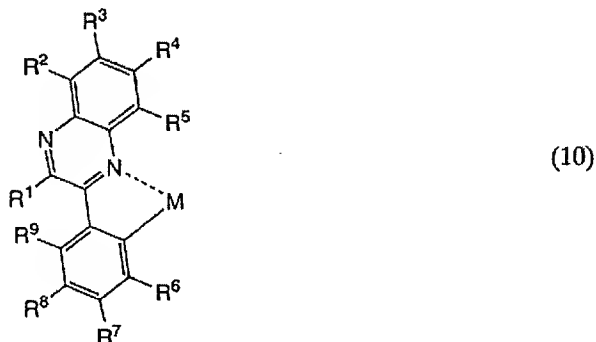


(In the formula, R<sup>1</sup> ~ R<sup>5</sup> are any of hydrogen, a halogen element, an acyl group, an alkyl group, an alkoxyl group, an aryl group, a cyano group, or a heterocyclic group, Ar is an aryl group having an electron-withdrawing substituent or a heterocyclic group having an electron-withdrawing substituent, and M is an element of Group 9 or an element of Group 10.)

[Claim 15]

A light-emitting element characterized by including a light-emitting layer which includes an organometallic complex represented by the general formula (10) and a compound that has a larger ionization potential and a smaller electron affinity than the organometallic complex between a pair of electrodes.

5 [Chemical Formula 10]

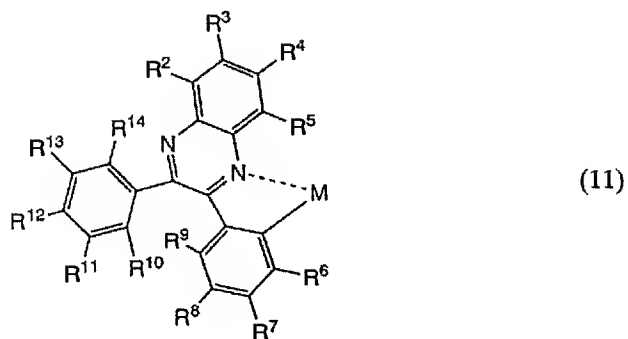


(In the formula,  $R^1 \sim R^9$  are any of hydrogen, a halogen element, an acyl group, an alkyl group, an alkoxyl group, an aryl group, a cyano group, or a heterocyclic group, and M is an element of Group 9 or an element of Group 10.)

10 [Claim 16]

A light-emitting element characterized by including a light-emitting layer which includes an organometallic complex including a structure represented by the general formula (11) and a compound that has a larger ionization potential and a smaller electron affinity than the organometallic complex between a pair of electrodes.

15 [Chemical Formula 11]

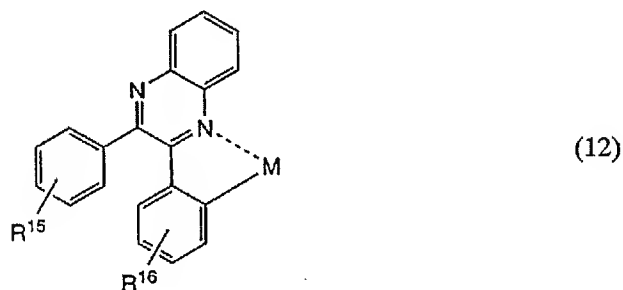


(In the formula,  $R^1 \sim R^{14}$  are any of hydrogen, a halogen element, an acyl group, an alkyl group, an alkoxyl group, an aryl group, a cyano group, or a heterocyclic group, and M is an element of Group 9 or an element of Group 10.)

[Claim 17]

A light-emitting element characterized by including a light-emitting layer which includes an organometallic complex including a structure represented by the general formula (12) and a compound that has a larger ionization potential and a smaller electron affinity than the organometallic complex between a pair of electrodes.

[Chemical Formula 12]

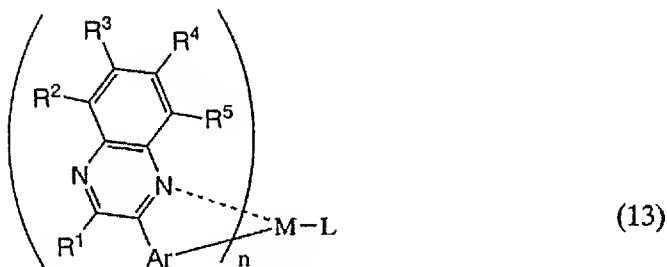


(In the formula,  $R^{15} \sim R^{16}$  are any of hydrogen, a halogen element, an acyl group, an alkyl group, an alkoxyl group, an aryl group, a cyano group, or a heterocyclic group, and M is an element of Group 9 or an element of Group 10.)

[Claim 18]

A light-emitting element characterized by including a light-emitting layer which includes an organometallic complex represented by the general formula (13) and a compound that has a larger ionization potential and a smaller electron affinity than the organometallic complex between a pair of electrodes.

[Chemical Formula 13]



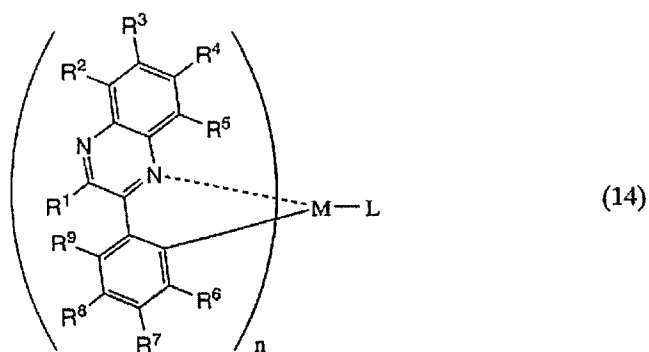
(In the formula,  $R^1 \sim R^5$  are any of hydrogen, a halogen element, an acyl group, an alkyl group, an alkoxyl group, an aryl group, a cyano group, or a heterocyclic group, Ar is an aryl group having an electron-withdrawing substituent or a heterocyclic group having an electron-withdrawing substituent, M is an element of Group 9 or an element

of Group 10,  $n = 2$  when the M is the element of Group 9 while  $n = 1$  when the M is the element of Group 10, and L is a monoanionic ligand.)

[Claim 19]

- 5 A light-emitting element characterized by including a light-emitting layer which includes an organometallic complex represented by the general formula (14) and a compound that has a larger ionization potential and a smaller electron affinity than the organometallic complex between a pair of electrodes.

[Chemical Formula 14]



- 10 (In the formula,  $R^1 \sim R^9$  are any of hydrogen, a halogen element, an acyl group, an alkyl group, an alkoxyl group, an aryl group, a cyano group, or a heterocyclic group. M is an element of Group 9 or an element of Group 10,  $n = 2$  when the M is the element of Group 9 while  $n = 1$  when the M is the element of Group 10, and L is a monoanionic ligand.)

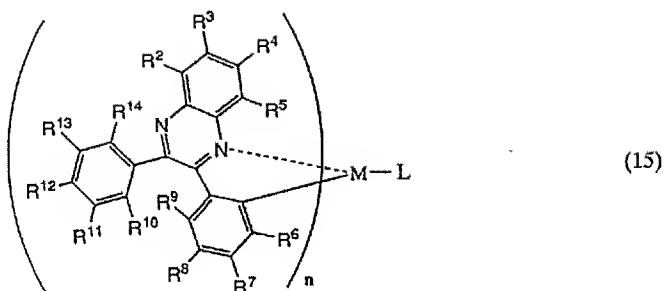
15 [Claim 20]

A light-emitting element characterized by including a light-emitting layer which includes an organometallic complex including a structure represented by the general formula (15) and a compound that has a larger ionization potential and a smaller electron affinity than the organometallic complex between a pair of electrodes.

20

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[Chemical Formula 15]

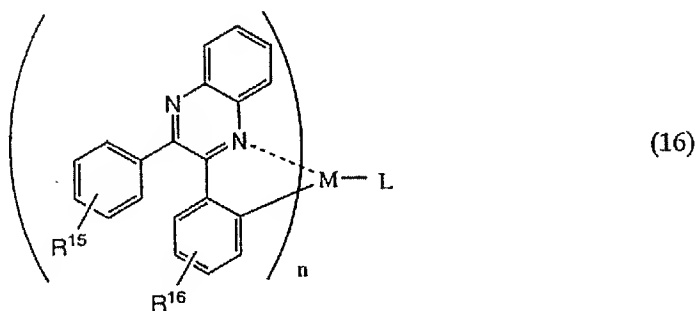


(In the formula,  $R^1 \sim R^{14}$  are any of hydrogen, a halogen element, an acyl group, an alkyl group, an alkoxyl group, an aryl group, a cyano group, or a heterocyclic group, M is an element of Group 9 or an element of Group 10,  $n = 2$  when the M is the element of Group 9 while  $n = 1$  when the M is the element of Group 10, and L is a monoanionic ligand.)

[Claim 21]

A light-emitting element characterized by including a light-emitting layer which includes an organometallic complex represented by the general formula (16) and a compound that has a larger ionization potential and a smaller electron affinity than the organometallic complex between a pair of electrodes.

[Chemical Formula 16]



(In the formula,  $R^1 \sim R^{14}$  are any of hydrogen, a halogen element, an acyl group, an alkyl group, an alkoxyl group, an aryl group, a cyano group, or a heterocyclic group, M is an element of Group 9 or an element of Group 10,  $n = 2$  when the M is the element of Group 9 while  $n = 1$  when the M is the element of Group 10, and L is a monoanionic ligand.)

[Claim 22]

The light-emitting element according to any one of claims 18 ~ 21, characterized in that the anionic ligand is a monoanionic ligand having a  $\beta$ -diketone structure, a monoanionic bidentate ligand having a carboxyl group, or a monoanionic bidentate ligand having a phenolic hydroxyl group.

5 [Claim 23]

The light-emitting element according to any one of claims 14 ~ 21, characterized in that any of a first compound that has a larger ionization potential and a smaller electron affinity than the organometallic complex and has an electron mobility of  $10^{-6}$  cm<sup>2</sup>/Vs or more or a second compound that has a larger ionization potential and  
10 a smaller electron affinity than the organometallic complex and has a hole mobility of  $10^{-6}$  cm<sup>2</sup>/Vs or more is included together with the organometallic complex.

[Claim 24]

The light-emitting element according to any one of claims 14 ~ 21, characterized in that a first compound that has a larger ionization potential and a smaller  
15 electron affinity than the organometallic complex and has an electron mobility of  $10^{-6}$  cm<sup>2</sup>/Vs or more and a second compound that has a larger ionization potential and a smaller electron affinity than the organometallic complex and has a hole mobility of  $10^{-6}$  cm<sup>2</sup>/Vs or more is included together with the organometallic complex.

[Claim 25]

20 The light-emitting element according to claim 23 or 24, characterized in that the first compound is a metal complex and the second compound is an aromatic amine compound.

[Claim 26]

The light-emitting element according to any one of claims 1 ~ 26, characterized  
25 by further including at least one layer of a hole injecting layer, a hole transporting layer, a hole blocking layer, an electron transporting layer, and an electron injecting layer.

[Claim 27]

A light-emitting device which uses the light-emitting element according to any one of claims 1 ~ 26.

[Document Name] Specification

[Title of the Invention] LIGHT EMITTING ELEMENT AND LIGHT EMITTING  
DEVICE

[Technical Field to which the Invention Pertains]

5 [0001]

The present invention relates to a light-emitting element using an organometallic complex that is capable of converting an excited triplet state into luminescence and a light-emitting device using the light-emitting element.

[Background Art]

10 [0002]

A light-emitting element using an organic compound is an element in which a layer including an organic compound (or an organic compound film) emits light by applying an electric field. The emission mechanism is said to be as follows: when a voltage is applied to electrodes with an organic compound film interposed therebetween,  
15 an electron injected from the cathode and a hole injected from the anode are recombined in the organic compound film to form a molecular exciton, and energy is released to emit light when the molecular exciton returns to the ground state.

[0003]

In such a light-emitting element, usually, an organic compound film is formed  
20 to be a thin film of approximately 1  $\mu\text{m}$  or less. In addition, since such a light-emitting element is a self light-emitting element in which an organic compound film itself emits light, a backlight as used for a conventional liquid crystal display is not necessary. Therefore, such a light-emitting element has the big advantage of being able to be manufactured to be thin and lightweight. In addition, for example, in an organic  
25 compound film on the order of 100 ~ 200 nm, the time from injection of carriers to recombination is approximately several tens of nanoseconds in consideration of the carrier mobility of the organic compound film, and light gets to be emitted on the order of within microseconds even when the process from the recombination of the carriers to light emission is included. Therefore, it is also one of features that the response speed  
30 is quite fast. Further, since such a light-emitting element is a carrier-injection light-emitting element, driving by a direct voltage is possible, and noise is unlikely to be

generated. As for the driving voltage, a sufficient luminance of 100 cd/m<sup>2</sup> is achieved at 5.5 V when an organic compound film is a uniform thin film of approximately 100 nm in thickness, an electrode material is selected so as to reduce the carrier injection barrier for the organic compound film, and further, a heterostructure (a two-layer structure here) is introduced (for example, refer to Non-Patent Reference 1).

[0004]

[Non-Patent Reference 1] C. W. Tang, et al., Applied Physics Letters, vol. 51, No. 12, pp. 913-915 (1987)

[0005]

10 In addition to such element characteristics such as slimness, lightweight, high-speed response, and direct-current low-voltage driving, it can be also said to be one of big advantages that the luminescent color of a light-emitting element using an organic compound is rich in variation, and the factor is the variety of organic compound themselves. Namely, the flexibility of being able to develop materials for various  
15 luminescent colors by molecular design (for example, introduction of a substituent) or the like produces richness of colors. It can be said that the biggest application field of a light-emitting element utilizing this richness of colors is a full-color flat-panel display because there are a lot of organic compounds capable of emitting light's three primary colors of red, green, and blue, and thus, full-color images can be achieved easily by  
20 patterning of the organic compounds.

[0006]

It can be said that the above-described element characteristics such as slimness, lightweight, high-speed response, and direct-current low-voltage driving are also appropriate characteristics for a flat-panel display. However, in recent years, the use of  
25 not fluorescent materials but phosphorescent materials has been tried as an attempt to further improve an emission efficiency. In the case of a light-emitting element using an organic compound, luminescence is produced when a molecular exciton returns to the ground state, where the luminescence can be luminescence (fluorescence) from an excited singlet state (S\*) and luminescence (phosphorescence) from an excited triplet  
30 state (T\*). When a fluorescent material is used, only luminescence (fluorescence) from S\* contributes.



[0007]

However, it is commonly believed that the statistical generation ratio between  $S^*$  and  $T^*$  in a light-emitting element is  $S^* : T^* = 1 : 3$  (for example, refer to Non-Patent Reference 2). Accordingly, in the case of a light-emitting element using a fluorescent material, the theoretical limit of the internal quantum efficiency (the ratio of generated photons to injected carriers) is considered to be 25 % on the ground of being  $S^* : T^* = 1 : 3$ . In other words, in the case of a light-emitting element using a fluorescent material, at least 75 % of injected carriers are wasted uselessly.

[0008]

- 10 [Non-Patent Reference 2] Tetsuo TSUTSUI, Textbook for the 3<sup>rd</sup> Workshop, Division of Molecular Electronics and Bioelectronics, Japan Society of Applied Physics, p. 31 (1993)

[0009]

- Conversely, it is believed that the emission efficiency is improved (simply 3 ~ 4 times) when luminescence from  $T^*$ , that is, phosphorescence can be used. However, in the case of a commonly used organic compound, luminescence (phosphorescence) from  $T^*$  is not observed at room temperature, and normally, only luminescence (fluorescence) from  $S^*$  is observed. This is because the ground state of an organic compound is normally a singlet ground state ( $S_0$ ), and thus,  $T^* \rightarrow S_0$  transition is a forbidden transition and  $S^* \rightarrow S_0$  transition is an allowed transition. In reality, in recent years, light-emitting elements in which energy (hereinafter, referred to as “triplet excitation energy”) that is emitted on returning from  $T^*$  to a ground state can be converted into luminescence have been released one after another, and their high emission efficiency have been attracting attention (for example, refer to Non-Patent Reference 3).
- 15  
20  
25

[0010]

[Non-Patent Reference 3] Tetsuo TSUTSUI, and 8 others, Japanese Journal of Applied Physics, vol. 38, L1502-L1504 (1999)

[0011]

- 30 In Non-Patent Reference 3, a metal complex including iridium as a central metal (hereinafter, referred to as “iridium complex”) is used as a luminescent material,

and it can be said to be a feature that an element of the third transition series is introduced as a central metal. These are materials (hereinafter, referred to as “triplet luminescent materials”) capable of converting an excited triplet state into luminescence at room temperature. As described in Non-Patent Document 3, a light-emitting element using an organic compound capable of converting triplet excitation energy into luminescence can achieve a higher internal quantum efficiency than a conventional one. Further, when the higher internal quantum efficiency can be achieved, the emission efficiency ( $\text{lm/W}$ ) is also improved.

[0012]

However, according to the report of Non-Patent Reference 3, the half-life of luminance is approximately 170 hours when the initial luminance is controlled to be  $500 \text{ cd/m}^2$  in constant current driving, and thus, a light-emitting element using a triplet luminescent material has a problem with the lifetime. On the other hand, in the case of a light-emitting element using a singlet luminescent material, the half-life of luminance reaches several thousands to ten thousands hours when the initial luminance is controlled to be  $500 \text{ cd/m}^2$  in constant current driving, and thus, it can be said that the light-emitting element reaches a practical level in terms of the lifetime.

[0013]

Accordingly, in a light-emitting element using a triplet luminescent material, an element that can be driven for a long time is desired. This is because a light-emitting element that is high in emission efficiency and has a long lifetime can be obtained.

[Disclosure of the Invention]

[Problems to be Solved by the Invention]

[0014]

The present invention is devised in view of the above-described background in order to solve such problems in the conventional techniques. In a light-emitting element using an organometallic complex capable of converting an excited triplet state into luminescence, it is an object to provide a light-emitting element that can be driven for a long time, that is, that is high in emission efficiency and has a long lifetime. Further, it is an object to provide a light-emitting device that has low power consumption by using the light-emitting element.

[Means for Solving the Problems]

[0015]

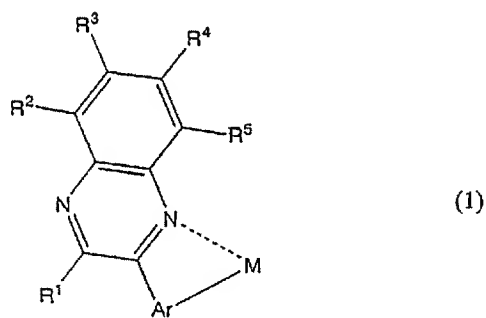
A lot of earnest experiments and studies by the inventors to achieve the objects have finally found out that, in a light-emitting element formed by providing a pair of electrodes which are an anode and a cathode and one or plural layers including an organic compound between the pair of electrodes, a light-emitting element that can be driven for a long time, that is, that is high in emission efficiency and has a long lifetime can be obtained when a specific compound is included in at least one layer of the layers including the organic compound, thereby completing the invention.

[0016]

In other words, a first invention of the present invention is a light-emitting element characterized by including a light-emitting layer which includes an organometallic complex including a partial structure represented by the general formula (1) and one of a compound that has a larger energy gap than the organometallic complex and a compound that has a larger ionization potential and a smaller electron affinity than the organometallic complex, between a pair of electrodes.

[0017]

[Chemical Formula 01]



(In the formula,  $R^1 \sim R^5$  are any of hydrogen, a halogen element, an acyl group, an alkyl group, an alkoxyl group, an aryl group, a cyano group, or a heterocyclic group, Ar is an aryl group having an electron-withdrawing substituent or a heterocyclic group having an electron-withdrawing substituent, and M is an element of Group 9 or an element of Group 10.)

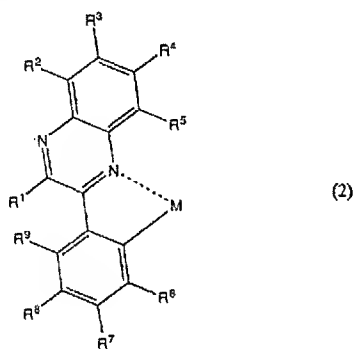
[0018]

A second invention of the present invention is a light-emitting element characterized by including a light-emitting layer which includes an organometallic

complex including a partial structure represented by the general formula (2) and one of a compound that has a larger energy gap than the organometallic complex and a compound that has a larger ionization potential and a smaller electron affinity than the organometallic complex, between a pair of electrodes.

5 [0019]

[Chemical Formula 02]



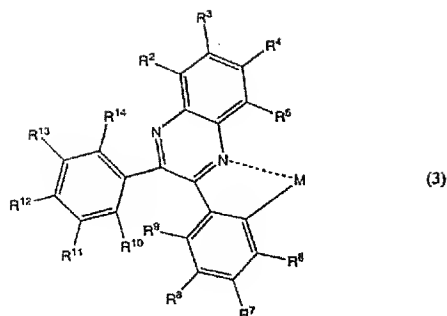
(In the formula,  $R^1 \sim R^9$  are any of hydrogen, a halogen element, an acyl group, an alkyl group, an alkoxyl group, an aryl group, a cyano group, or a heterocyclic group, any one of  $R^6$  to  $R^9$  is an electron-withdrawing substituent, and  $M$  is an element of Group 9 or an element of Group 10.)

[0020]

A third invention of the present invention is a light-emitting element characterized by including a light-emitting layer which includes an organometallic complex including a partial structure represented by the general formula (3) and one of a compound that has a larger energy gap than the organometallic complex and a compound that has a larger ionization potential and a smaller electron affinity than the organometallic complex, between a pair of electrodes.

[0021]

20 [Chemical Formula 03]



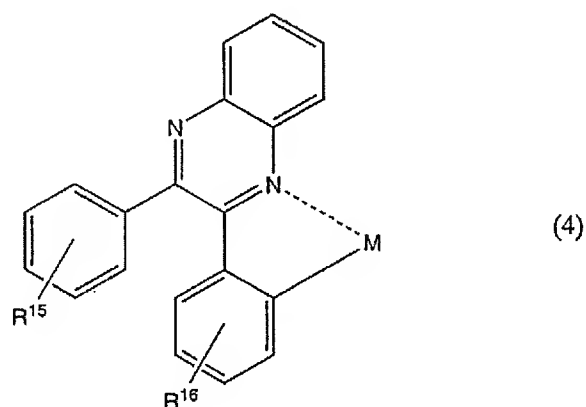
(In the formula,  $R^2 \sim R^{14}$  are any of hydrogen, a halogen element, an acyl group, an alkyl group, an alkoxy group, an aryl group, a cyano group, or a heterocyclic group, and M is an element of Group 9 or an element of Group 10.)

5 [0022]

A fourth invention of the present invention is a light-emitting element characterized by including a light-emitting layer which includes an organometallic complex including a partial structure represented by the general formula (4) and one of a compound that has a larger energy gap than the organometallic complex and a  
10 compound that has a larger ionization potential and a smaller electron affinity than the organometallic complex, between a pair of electrodes.

[0023]

[Chemical Formula 04]



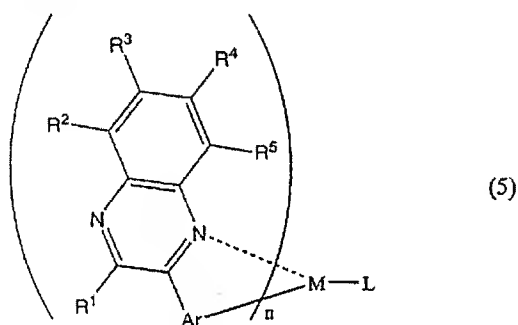
15 (In the formula,  $R^{15}$  and  $R^{16}$  are any of hydrogen, a halogen element, an acyl group, an alkyl group, an alkoxy group, an aryl group, a cyano group, or a heterocyclic group, and M is an element of Group 9 or an element of Group 10.)

[0024]

A fifth invention of the present invention is a light-emitting element characterized by including a light-emitting layer which includes an organometallic complex represented by the general formula (5) and one of a compound that has a larger energy gap than the organometallic complex and a compound that has a larger ionization potential and a smaller electron affinity than the organometallic complex,  
 5 between a pair of electrodes.

[0025]

[Chemical Formula 05]



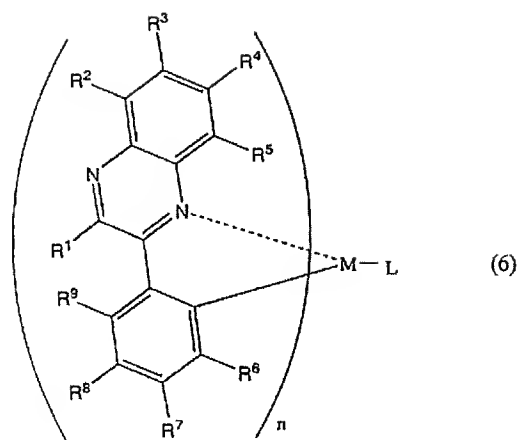
10 (In the formula,  $R^1 \sim R^5$  are any of hydrogen, a halogen element, an acyl group, an alkyl group, an alkoxyl group, an aryl group, a cyano group, or a heterocyclic group, Ar is an aryl group having an electron-withdrawing substituent or a heterocyclic group having an electron-withdrawing substituent, M is an element of Group 9 or an element of Group 10,  $n = 2$  when the M is the element of Group 9 while  $n = 1$  when the M is the  
 15 element of Group 10, and L is a monoanionic ligand.)

[0026]

A sixth invention of the present invention is a light-emitting element characterized by including a light-emitting layer which includes an organometallic complex represented by the general formula (6) and one of a compound that has a larger energy gap than the organometallic complex and a compound that has a larger  
 20 ionization potential and a smaller electron affinity than the organometallic complex, between a pair of electrodes.

[0027]

[Chemical Formula 06]



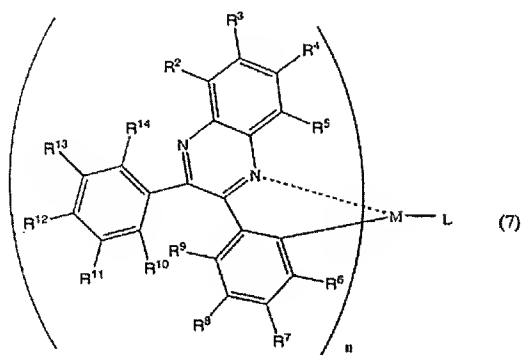
(In the formula,  $R^1 \sim R^9$  are any of hydrogen, a halogen element, an acyl group, an alkyl group, an alkoxy group, an aryl group, a cyano group, or a heterocyclic group. Note that at least one of  $R^6 \sim R^9$  is an electron-withdrawing substituent. M is an element of Group 9 or an element of Group 10,  $n = 2$  when the M is the element of Group 9 while  $n = 1$  when the M is the element of Group 10, and L is a monoanionic ligand.)

[0028]

A seventh invention of the present invention is a light-emitting element characterized by including a light-emitting layer which includes an organometallic complex represented by the general formula (7) and one of a compound that has a larger energy gap than the organometallic complex and a compound that has a larger ionization potential and a smaller electron affinity than the organometallic complex, between a pair of electrodes.

[0029]

[Chemical Formula 07]



(In the formula,  $R^2 \sim R^{14}$  are any of hydrogen, a halogen element, an acyl group, an alkyl group, an alkoxy group, an aryl group, a cyano group, or a heterocyclic group, M is an element of Group 9 or an element of Group 10,  $n = 2$  when the M is the element of Group 9 while  $n = 1$  when the M is the element of Group 10, and L is an anionic

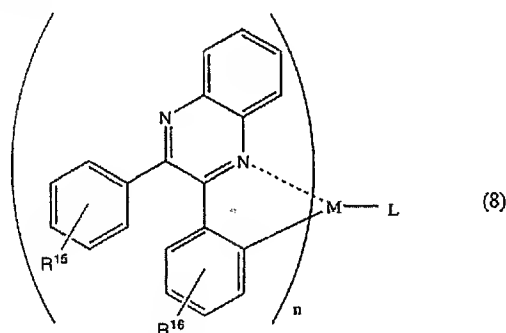
ligand.)

[0030]

A eighth invention of the present invention is a light-emitting element characterized by including a light-emitting layer which includes an organometallic complex represented by the general formula (8) and one of a compound that has a larger energy gap than the organometallic complex and a compound that has a larger ionization potential and a smaller electron affinity than the organometallic complex, between a pair of electrodes.

[0031]

[Chemical Formula 08]



(In the formula,  $R^{15}$  and  $R^{16}$  are any of hydrogen, a halogen element, an acyl group, an alkyl group, an alkoxy group, an aryl group, a cyano group, or a heterocyclic group, M is an element of Group 9 or an element of Group 10,  $n = 2$  when the M is the element of Group 9 while  $n = 1$  when the M is the element of Group 10, and L is an anionic ligand.)

[0032]

A (ninth) light-emitting element according to the present invention is a light-emitting element characterized in that, in any of the first ~ eighth light-emitting elements, the compound that has the larger energy gap than the organometallic complex is 4,4'-bis[N-(1-naphthyl)-N-phenylamino]biphenyl or tris(8-quinolinolato)aluminum.



[0033]

A (tenth) light-emitting element according to the present invention is a light-emitting element characterized in that, in any of the fifth ~ eighth light-emitting elements, the anionic ligand is a monoanionic ligand having a  $\beta$ -diketone structure, a  
5 monoanionic bidentate ligand having a carboxyl group, or a monoanionic bidentate ligand having a phenolic hydroxyl group.

[0034]

An (eleventh) light-emitting element according to the present invention is a light-emitting element characterized in that, in any of the first ~ eighth light-emitting  
10 elements, a first compound that has a larger energy gap than the organometallic complex and has an electron mobility of  $10^{-6}$  cm<sup>2</sup>/Vs or more and/or a second compound that has a larger energy gap than the organometallic complex and has a hole mobility of  $10^{-6}$  cm<sup>2</sup>/Vs or more is/are included together with the organometallic complex.

[0035]

15 A (twelfth) light-emitting element according to the present invention is a light-emitting element characterized in that, in any of the first ~ eighth light-emitting elements, a first compound that has a larger ionization potential and a smaller electron affinity than the organometallic complex and has an electron mobility of  $10^{-6}$  cm<sup>2</sup>/Vs or more and/or a second compound that has a larger ionization potential and a smaller  
20 electron affinity than the organometallic complex and has a hole mobility of  $10^{-6}$  cm<sup>2</sup>/Vs or more is/are included together with the organometallic complex.

[0036]

A (thirteenth) light-emitting element according to the present invention is a light-emitting element characterized in that, in the eleventh or twelfth light-emitting  
25 element, a hole transporting compound is an aromatic amine compound, and an electron transporting compound is a metal complex.

[0037]

A (fourteenth) light-emitting element according to the present invention is a light-emitting element characterized by further including at least one layer of a hole  
30 injecting layer, a hole transporting layer, a hole blocking layer, an electron transporting layer, and an electron injecting layer in any of the first ~ thirteenth light-emitting

elements.

[0038]

In addition, a light-emitting device according to the present invention is a light-emitting device manufactured by using any of the first ~ fourteenth light-emitting  
5 elements.

[Effect of the Invention]

[0039]

A light-emitting element that has a light-emitting layer including the organometallic complex and a compound that has a larger energy gap than the  
10 organometallic complex can be driven for a long time, is high in emission efficiency, and has a long lifetime. In addition, a light-emitting device that uses the light-emitting element according to the present invention has, therefore, excellent performance as a light-emitting device.

[Best Mode for Carrying Out the Invention]

15 [0040]

The present invention will be described in more detail below. First, organometallic complexes used in the present invention will be described. The present invention provides a novel organometallic complex, a light-emitting element using the organometallic complex, and a light-emitting device using the light-emitting element.

20 [0041]

Specific examples of the substituents  $R^1 \sim R^{16}$  described above are as follows. The acyl group includes an acetyl group, a propionyl group, an isobutyryl group, a methacryloyl group, and the like. The alkyl group includes a methyl group, an ethyl group, an n-propyl group, an iso-propyl group, a tert-butyl group, an octyl group, and  
25 the like. The alkoxyl group includes a methoxy group, an ethoxy group, a propoxy group, and the like. The aryl group includes a phenyl group, a 4-methylphenyl group, a 4-ethylphenyl group, and the like. The heterocyclic group includes a pyridyl group, bipyridyl group, a methylpyridyl group, and the like. The electron-withdrawing substituent includes a fluoro group, a trifluoromethyl group, a cyano group, and the like.

30 [0042]

In addition, specific examples of the element of Group 9 or the element of

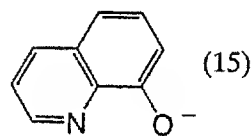
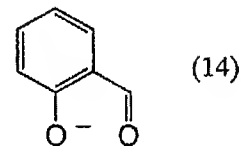
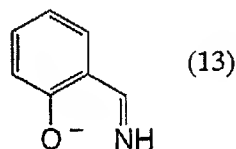
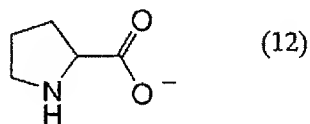
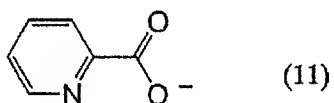
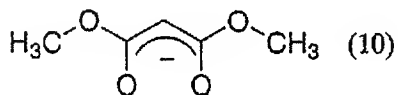
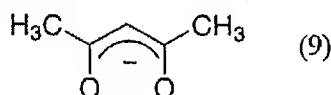
Group 10 include iridium, platinum, and the like. However, the element of Group 9 or the element of Group 10 is not to be considered limited to these elements given as examples.

[0043]

- 5 Then, as specific examples of a monoanionic ligand having a  $\beta$ -diketone structure, a monoanionic bidentate ligand having a carboxyl group, and a monoanionic bidentate ligand having a phenolic hydroxyl group, examples of the following (9) ~ (15) can be given.

[0044]

- 10 [Chemical Formula 09]

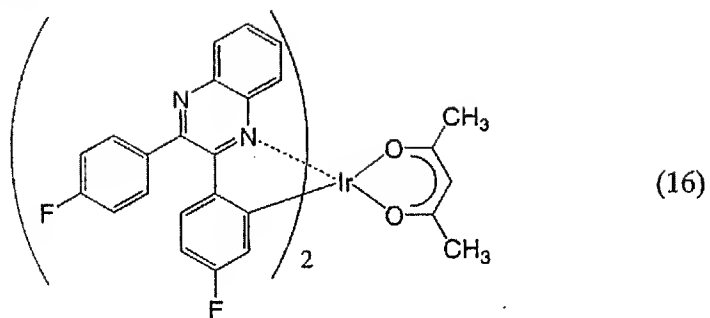


[0045]

- Further, typical examples of organometallic complexes including a partial structure represented by the general formulas (1) ~ (4), that is, organometallic complexes represented by the general formulas (5) ~ (8) are given below. However,
- 15 the organometallic complexes are not to be considered limited to these compounds.

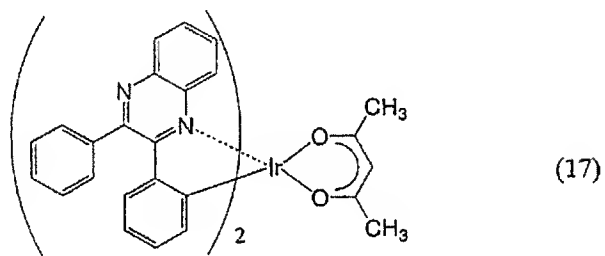
[0046]

[Chemical Formula 10]



[0047]

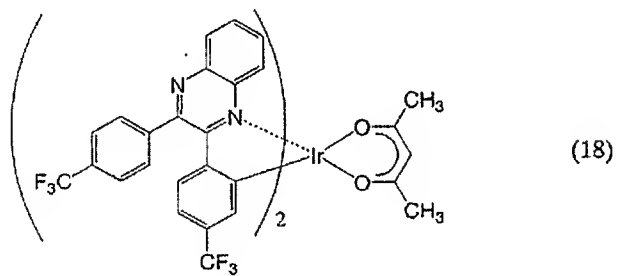
[Chemical Formula 11]



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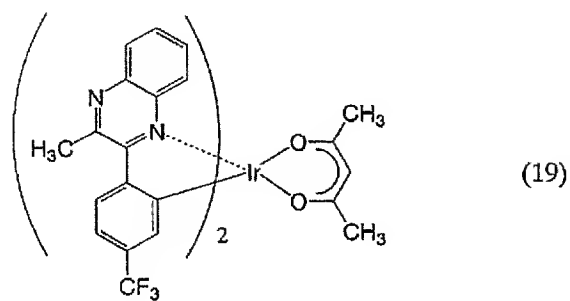
[0048]

[Chemical Formula 12]



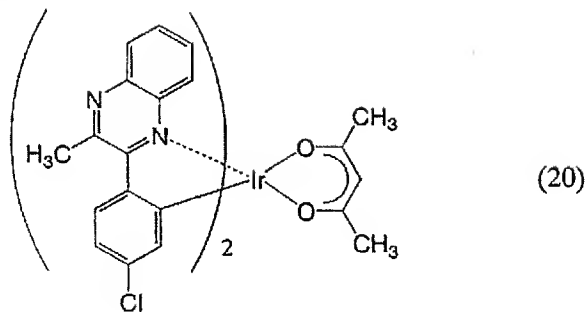
[0049]

10 [Chemical Formula 13]



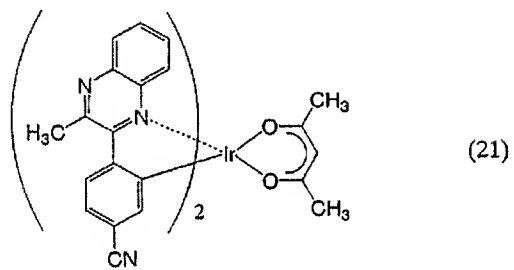
[0050]

[Chemical Formula 14]



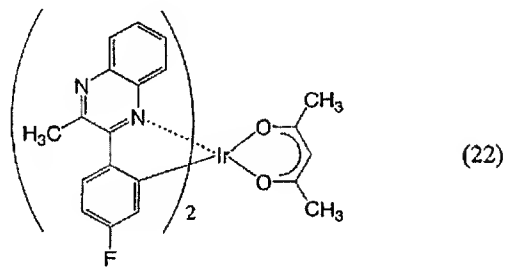
[0051]

5 [Chemical Formula 15]



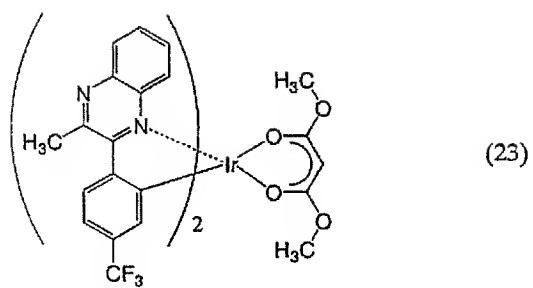
[0052]

[Chemical Formula 16]



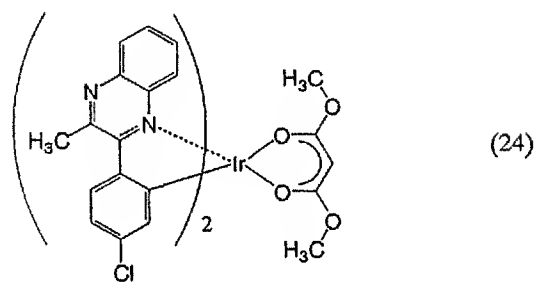
10 [0053]

[Chemical Formula 17]



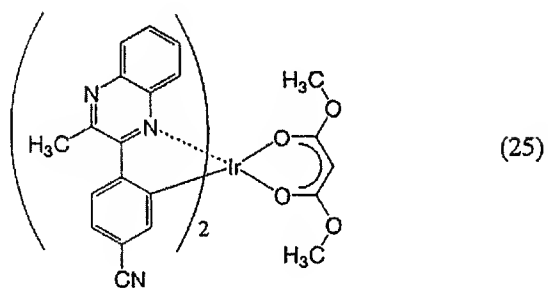
[0054]

[Chemical Formula 18]



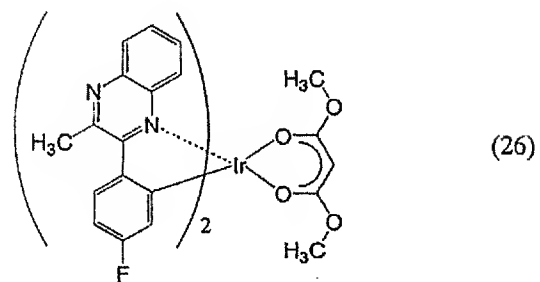
5 [0055]

[Chemical Formula 19]



[0056]

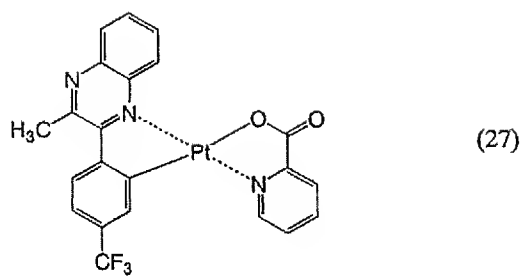
[Chemical Formula 20]



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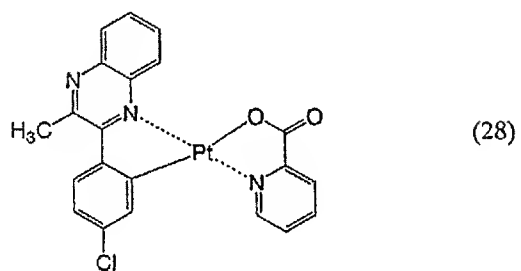
[0057]

[Chemical Formula 21]



[0058]

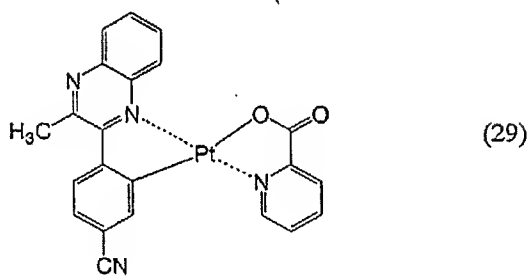
[Chemical Formula 22]



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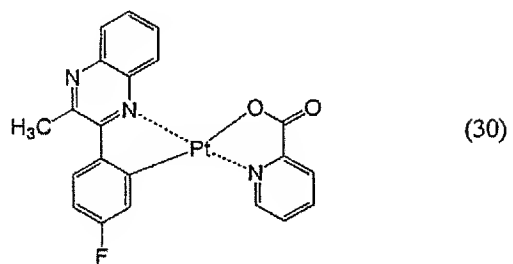
[0059]

[Chemical Formula 23]



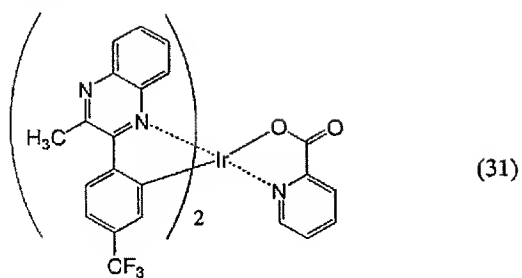
[0060]

10 [Chemical Formula 24]



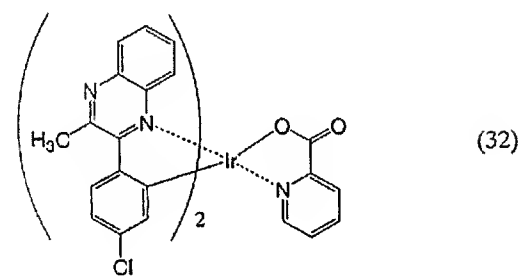
[0061]

[Chemical Formula 25]



[0062]

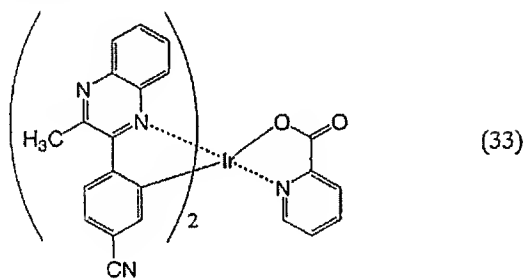
[Chemical Formula 26]



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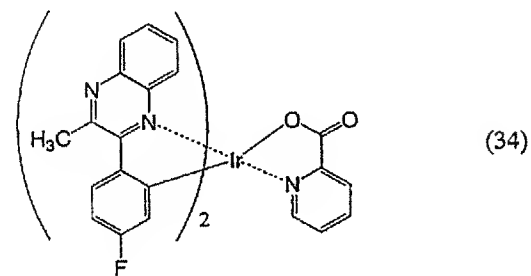
[0063]

[Chemical Formula 27]



[0064]

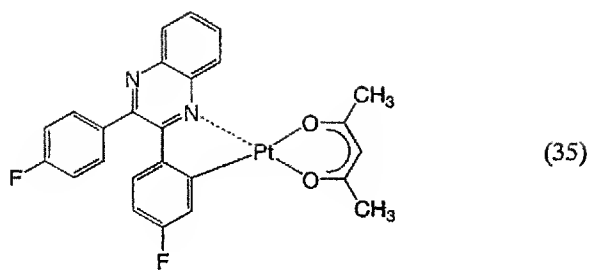
10 [Chemical Formula 28]



[0065]

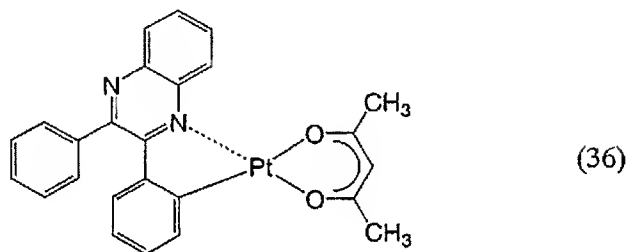


[Chemical Formula 29]



[0066]

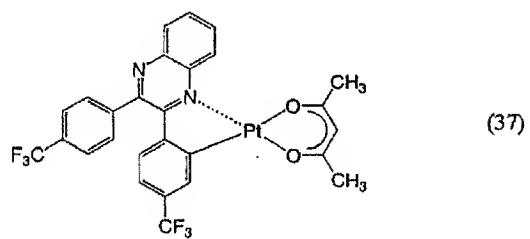
[Chemical Formula 30]



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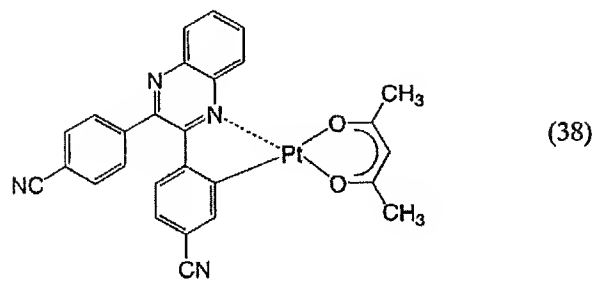
[0067]

[Chemical Formula 31]



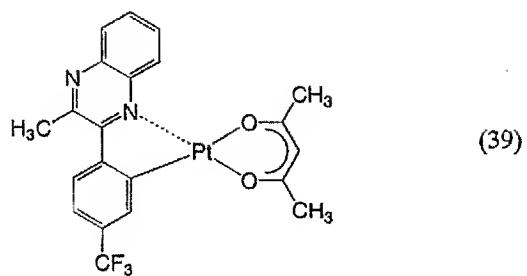
[0068]

10 [Chemical Formula 32]



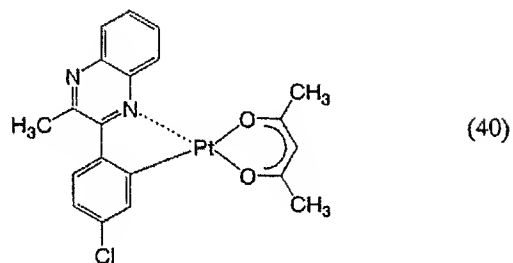
[0069]

[Chemical Formula 33]



[0070]

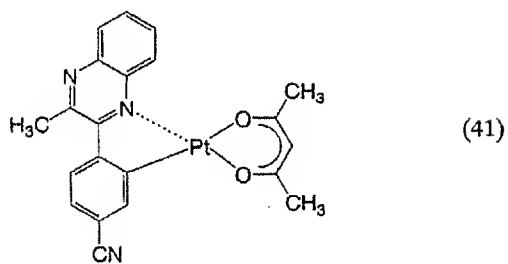
[Chemical Formula 34]



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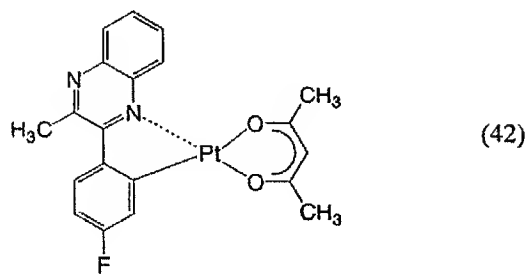
[0071]

[Chemical Formula 35]



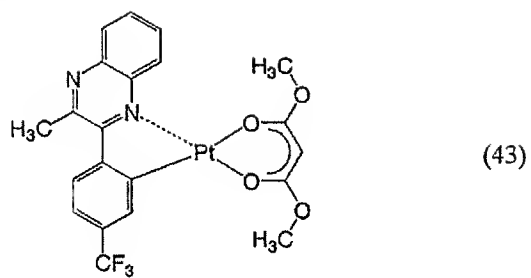
[0072]

10 [Chemical Formula 36]



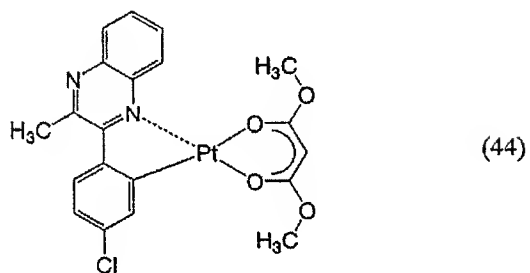
[0073]

[Chemical Formula 37]



[0074]

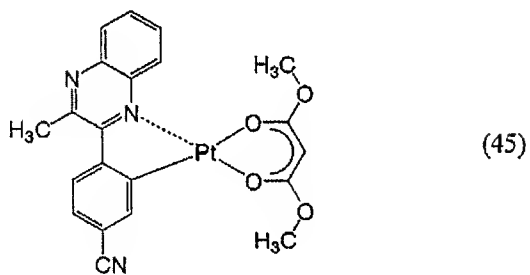
[Chemical Formula 38]



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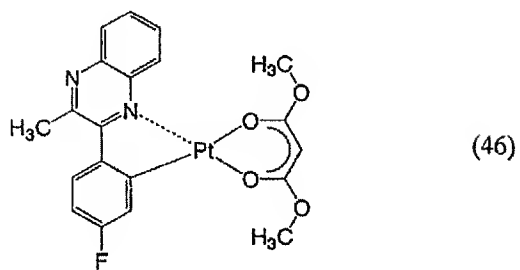
[0075]

[Chemical Formula 39]



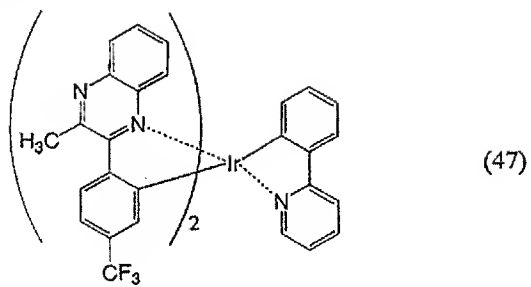
[0076]

10 [Chemical Formula 40]



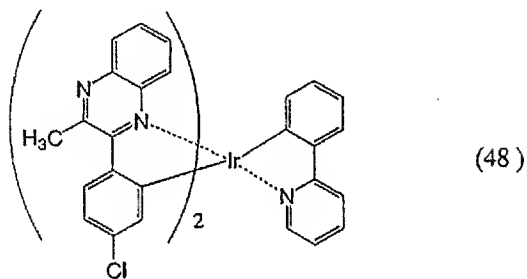
[0077]

[Chemical Formula 41]



[0078]

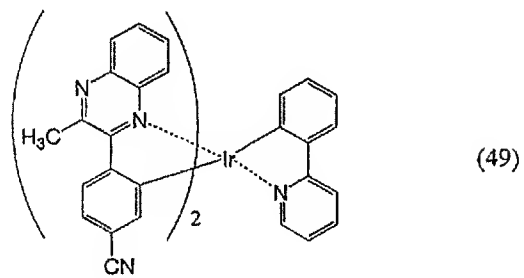
[Chemical Formula 42]



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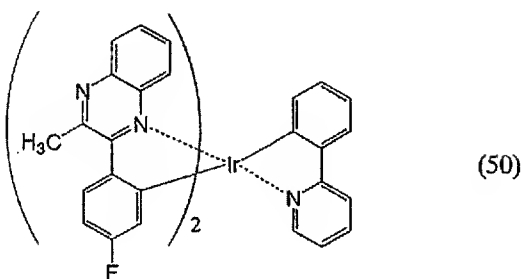
[0079]

[Chemical Formula 43]



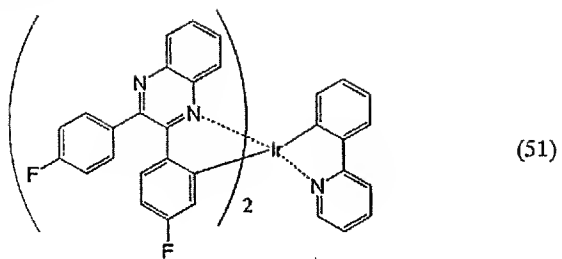
[0080]

10 [Chemical Formula 44]



[0081]

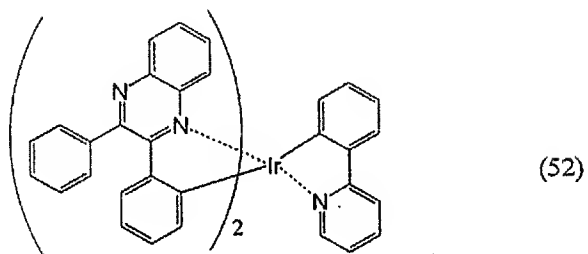
[Chemical Formula 45]



(51)

[0082]

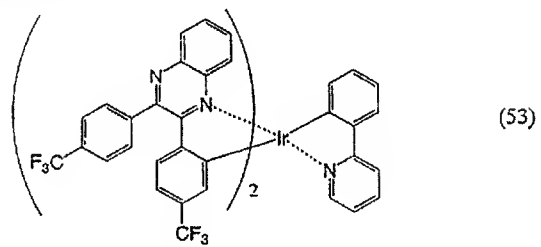
5 [Chemical Formula 46]



(52)

[0083]

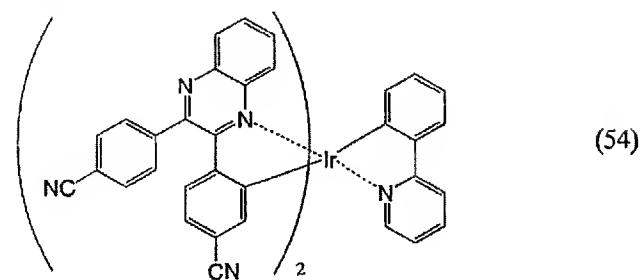
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(53)

10 [0084]

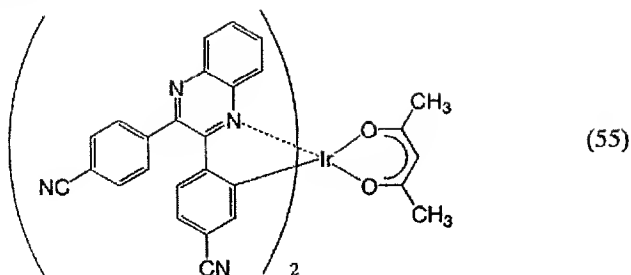
[Chemical Formula 48]



(54)

[0085]

[Chemical Formula 49]

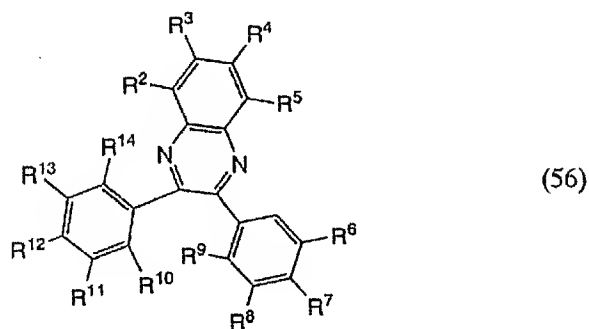


[0086]

5        Next, a manufacturing method of an organometallic complex used in the present invention will be described. An organometallic complex used in the present invention, that is, an organometallic complex represented by the general formulas (1) ~ (8) can be obtained by orthometallation of a ligand. For example, an organometallic complex including a ligand represented by the following general formula (56), that is,  
10    an organometallic complex represented by the general formula (3) or (7) can be obtained by orthometallation reaction of the ligand represented by the following general formula (56). A method for synthesizing an organometallic complex represented by the general formula (7) with the use of the ligand represented by the general formula (56) will be described below.

15    [0087]

[Chemical Formula 50]



(In the formula,  $R^2 \sim R^{14}$  are any of hydrogen, a halogen element, an acyl group, an alkyl group, an alkoxyl group, an aryl group, a cyano group, or a heterocyclic group.)

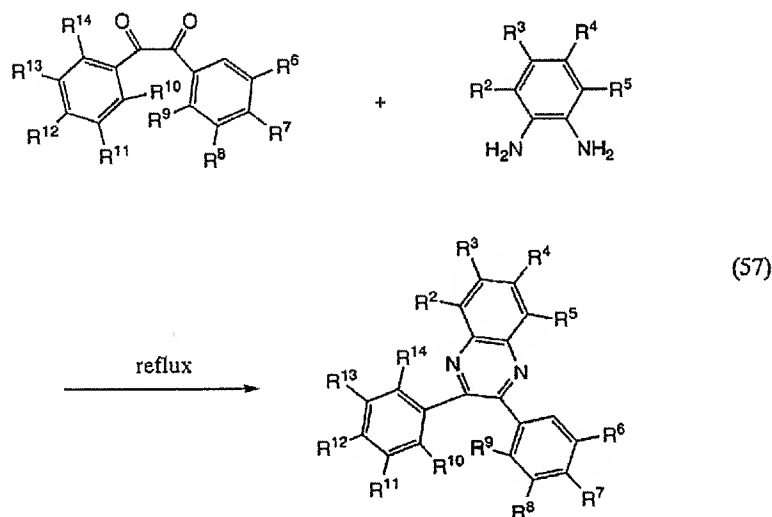
20    [0088]

It is to be noted that the ligand represented by the general formula (56) can be

synthesized, for example, in accordance with the following synthesis scheme (57). In addition, another ligand in an organometallic complex used in the present invention can be synthesized in a similar way.

[0089]

5 [Chemical Formula 51]



(In the formula, R<sup>2</sup> ~ R<sup>14</sup> are any of hydrogen, a halogen element, an acyl group, an alkyl group, an alkoxy group, an aryl group, a cyano group, or a heterocyclic group.)

[0090]

10 The thus obtained ligand represented by the general formula (56) is used to synthesize an organometallic complex used in the present invention. The following synthesis method may be used for a reaction (orthometallation) at this time.

[0091]

For example, when an organometallic complex used in the present invention is synthesized with iridium as a central metal, a chloro-bridged dinuclear complex is first synthesized with the use of iridium chloride hydrate as a raw material for the central metal by mixing the iridium chloride hydrate with the ligand represented by the general formula (56) and holding the iridium chloride hydrate mixed with the ligand at reflux in a nitrogen atmosphere [the following synthesis scheme (58)]. Next, by mixing the obtained dinuclear complex with a ligand L and holding the dinuclear complex mixed with the ligand L at reflux in a nitrogen atmosphere, the chlorine bridge is cut with the ligand L to obtain an organometallic complex used in the present invention [the

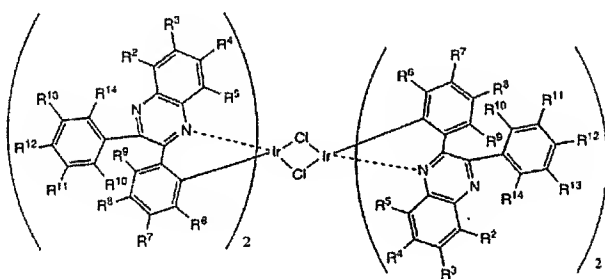
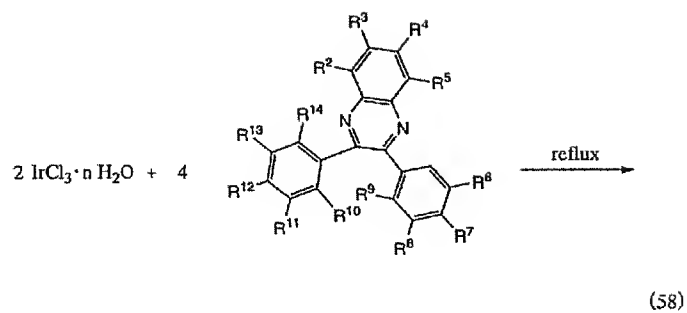
15

20

following synthesis scheme (59)].

[0092]

[Chemical Formula 52]

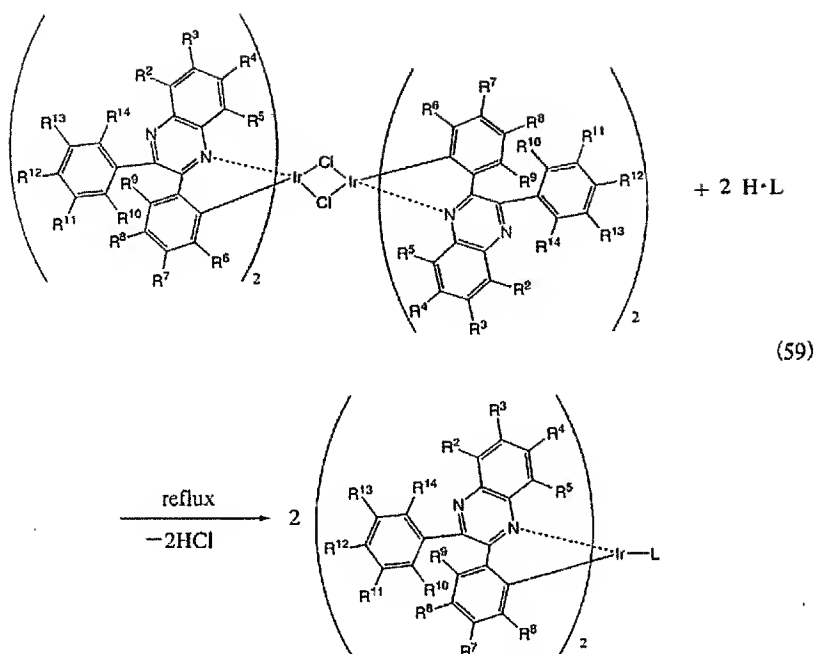


- 5 (In the formula,  $R^2 \sim R^{14}$  are any of hydrogen, a halogen element, an acyl group, an alkyl group, an alkoxy group, an aryl group, a cyano group, or a heterocyclic group.)

[0093]

[Chemical Formula 53]





(In the formula,  $R^2 \sim R^{14}$  are any of hydrogen, a halogen element, an acyl group, an alkyl group, an alkoxy group, an aryl group, a cyano group, or a heterocyclic group.)  
[0094]

5        It is to be noted that the synthesis method of an organometallic complex used in the present invention is not to be considered limited to the synthesis method described above.

[0095]

10        Next, light-emitting elements according to the present invention will be described with reference to the drawings.

[0096]

<Embodiment Mode 1>

In Embodiment mode 1, a light-emitting element according to the present invention will be described with reference to FIG. 1.

15        As shown in FIG. 1, the light-emitting element according to the present invention has a structure in which a first electrode 101 is formed on a substrate 100, a layer 102 including a luminescent material is formed on the first electrode 101, and a second electrode 103 is formed thereon. As a material to be used for the substrate 100 here, a material that is used for a conventional light-emitting element may be used.

For example, a material formed of glass, quartz, transparent plastic, a flexible substrate, or the like can be used. In addition, the first electrode 101 and the second electrode 103 in Embodiment mode 1 function as an anode and a cathode, respectively.

[0097]

5           Namely, the first electrode 101 is formed using an anode material. As the anode material that can be used here, it is preferable to use a metal, an alloy, an electrically conductive compound, or a mixture thereof, which has a larger work function (a work function of 4.0 eV or more). As specific examples of the anode material, gold (Au), platinum (Pt), nickel (Ni), tungsten (W), chromium (Cr),  
10   molybdenum (Mo), iron (Fe), cobalt (Co), copper (Cu), or palladium (Pd); a nitride of a metal material (TiN); and the like can be used in addition to ITO (indium tin oxide), ITSO (indium tin silicon oxide), and IZO (indium zinc oxide) of indium oxide mixed with zinc oxide (ZnO) at 2 ~ 20 [%].

[0098]

15           On the other hand, as a cathode material to be used for formation of the second electrode 103, it is preferable to use a metal, an alloy, an electrically conductive compound, or a mixture thereof, which has a smaller work function (a work function of 3.8 eV or less). As specific examples of the cathode material, in addition to an element belonging to Group 1 or 2 of the periodic table of the elements, that is, alkali  
20   metals such as Li and Cs and alkali-earth metals such as Mg, Ca, and Sr, and an alloy (Mg:Ag or Al:Li) and a compound (LiF, CsF, or CaF<sub>2</sub>) including these elements, a transition metal including a rare-earth metal can be used to form the second electrode 103. The second electrode 103 can be formed also by stacking a layer of a metal (including an alloy) such as Al, Ag, or ITO.

25   [0099]

Thin films are formed using the above-mentioned anode material and the cathode material by a method such as evaporation or sputtering to form the first electrode 101 and the second electrode 103, which preferably have a film thickness of 10 ~ 500 nm. Finally, a protective layer (a barrier layer) composed of an inorganic  
30   material such as SiN or an organic material such as Teflon (registered trademark) or a styrene polymer is formed. The barrier layer may be transparent or non-transparent,

and the inorganic material or organic material is formed by a method such as evaporation or sputtering.

[0100]

In the light-emitting element according to the present invention, light generated  
5 by recombination of carriers in a light-emitting layer is emitted from one or both of the first electrode 101 and the second electrode 103 to the outside. Namely, the first electrode 101 is formed using a light-transmitting material when the light is emitted from the first electrode 101 while the second electrode 103 is formed using a light-transmitting material when the light is emitted from the second electrode 103 side.  
10 The layer 102 including the luminescent material is formed by stacking a plurality of layers, in Embodiment mode 1, by stacking a hole injecting layer 111, a hole transporting layer 112, a light-emitting layer 113, a hole blocking layer 114, and an electron transporting layer 115 in order.

[0101]

15 In the layer 102 including the luminescent material, the hole injecting layer 111 is provided to come in contact with the first electrode 101. In addition, it is preferable to form the hole injecting layer 111 with the use of a material that is capable of receiving holes from the first electrode 101. Further, it is preferable to form the hole injecting layer 111 using a material that is capable of injecting holes into a layer that is  
20 in contact with the hole injecting layer 111 and provided on the second electrode 103 side of the hole injecting layer 111. Specifically, it is preferable to form the hole injecting layer 111 with the use of a phthalocyanine compound. The phthalocyanine compound includes, for example, phthalocyanine (abbreviation: H<sub>2</sub>-Pc), copper phthalocyanine (abbreviation: Cu-Pc), and the like.

25 [0102]

In addition, an aromatic amine compound such as 4,4'-bis[N-(4-(N,N-di-m-tolylamino)phenyl)-N-phenylamino]biphenyl (abbreviation: DNTPD) or 4,4',4''-tris[N-(3-methylphenyl)-N-phenylamino]triphenylamine (abbreviation: MTDATA) can also be used. In addition, conductive inorganic  
30 compounds (including semiconductors) such as molybdenum oxide (MoOx) and vanadium oxide (VOx) can be also used. Further, a mixture of the conductive inorganic compound and the aromatic amine compound described above or below can

be used. This mixture can be formed by a method such as co-evaporation.

[0103]

It is preferable to form the hole transporting layer 112 with the use of a material that is capable of transporting holes, specifically, an aromatic amine compound (that is, a compound having a benzene ring-nitrogen bond). For example, in addition to 4,4'-bis[N-(3-methylphenyl)-N-phenyl-amino]-biphenyl (abbreviation: TPD) and 4,4'-bis[N-(1-naphthyl)-N-phenyl-amino]-biphenyl (abbreviation:  $\alpha$ -NPD), starburst aromatic amine compounds such as MTDATA mentioned above and 4,4',4''-tris(N,N-diphenyl-amino)-triphenylamine (abbreviation: TDATA) are preferably used to form the hole transporting layer 112. In addition, a mixture of a conductive inorganic compound (including semiconductors) such as molybdenum oxide (MoOx) or vanadium oxide (VOx) and the aromatic amine compound described above can be used. This mixture can be formed by a method such as co-evaporation.

[0104]

It is preferable that the light-emitting layer 113 be formed by co-evaporation of a host material and at least one organometallic complex among the organometallic complexes including a partial structure represented by the general formulas (1) ~ (4) and the organometallic complexes represented by the general formulas (5) ~ (8). As the host material, it is preferable to use a material that has a larger energy gap ( $E_g$ ) than the at least one organometallic complex which is selected from the organometallic complexes including a partial structure represented by the general formulas (1) ~ (4) and the organometallic complexes represented by the general formulas (5) ~ (8).

[0105]

In addition, in particular, as the host material, it is preferable to use a material that has a larger energy gap and further has a larger ionization potential ( $I_p$ ) and a smaller electron affinity (EA) than the at least one organometallic complex which is selected from the organometallic complexes including a partial structure represented by the general formulas (1) ~ (4) and the organometallic complexes represented by the general formulas (5) ~ (8). As examples thereof, 4,4'-bis(N-carbazolyl)-biphenyl (abbreviation: CBP), 4,4',4''-tris(N-carbazolyl)-triphenylamine (abbreviation: TCTA), and 1,3,5-tris[4-(N-carbazolyl)phenyl]benzene (abbreviation: TCPB) can be given.

Further, it is more preferable that the host material be composed of a material that is capable of transporting either one or both carriers of a hole and an electron, specifically, a material that has a carrier mobility of  $10^{-6}$  cm<sup>2</sup>/Vs or more. This makes it possible to reduce the driving voltage and improve the reliability of the element.

5 [0106]

Specific examples of materials that can be used as the host material include  $\alpha$ -NPD and tris(8-quinolinolato)aluminum (abbreviation: Alq<sub>3</sub>). It is to be noted that the hole mobility in  $\alpha$ -NPD is approximately  $10^{-4}$  cm<sup>2</sup>/Vs, and that the electron mobility in tris(8-quinolinolato)aluminum (abbreviation: Alq<sub>3</sub>) is approximately  $10^{-5}$  cm<sup>2</sup>/Vs. As described above, it is preferable that the mobilities of either one or both carriers of a hole and an electron be  $10^{-6}$  cm<sup>2</sup>/Vs or more. However, the host material is not to be considered limited to  $\alpha$ -NPD and Alq<sub>3</sub>, and the above-mentioned aromatic amine compounds such as TPD and metal complexes such as tris(8-quinolinolato)gallium (abbreviation: Gaq<sub>3</sub>) and tris(4-methyl-8-quinolinolato)aluminum (abbreviation: Almq<sub>3</sub>) can be also used as the host material. These materials, Alq<sub>3</sub>, Gaq<sub>3</sub>, and Almq<sub>3</sub>, correspond to specific examples of electron transporting metal complexes.

[0107]

When the light-emitting layer 113 is formed to have the structure described above, holes and electrons are easily transported in the light-emitting layer 113, and moreover those holes and electrons are efficiently trapped by the organometallic complex without passing through the light-emitting layer to produce luminescence. Therefore, it is not easy for holes or electrons to pass through the light-emitting layer, and exciton formation is made more efficient. Accordingly, a stable device that shows less decrease in emission efficiency (that is, deterioration in luminance) can be constructed.

[0108]

The organometallic complexes represented by the structure formulas (16) ~ (55) easily receive holes due to the organic moiety-metal bond, and further, also easily receive electrons due to the quinoxaline skeleton. Therefore, the organometallic complexes have the advantage that carriers can be trapped effectively.

[0109]

It is to be noted that it is preferable to form the light-emitting layer 113 with the use of an organometallic complex having a fluoro group or a trifluoromethyl group, particularly like (16) and (18) among the organometallic complexes represented by the structure formulas (16) ~ (55). This expands the range of choices for the host materials. In addition, in particular, the affinity for electrons is increased to provide the advantage that electrons can be trapped more effectively.

[0110]

It is preferable to form the hole blocking layer 114 with the use of a material that has a large ionization potential such as bis(2-methyl-8-quinolinolato)-4-phenylphenolato-aluminum (abbreviation: BAlq), 1,3-bis[5-(p-tert-butylphenyl)-1,3,4-oxadiazole-2-yl]benzene (abbreviation: OXD-7), 3-(4-tert-butylphenyl)-4-phenyl-5-(4-biphenyl)-1,2,4-triazole (abbreviation: TAZ), 3-(4-tert-butylphenyl)-4-(4-ethylphenyl)-5-(4-biphenyl)-1,2,4-triazole (abbreviation: p-EtTAZ), bathophenanthroline (abbreviation: BPhen), or bathocuproine (abbreviation: BCP), and more preferable to form the hole blocking layer 114 with the use of a material that has an 0.3 eV or more larger ionization potential than the light-emitting layer 113. This makes it possible to prevent holes injected from the first electrode side into the layer including the luminescent material from flowing toward the side of the electrode serving as a cathode. In addition, light energy can be prevented from transferring toward the electron transporting layer.

[0111]

It is preferable to form the electron transporting layer 115 with the use of a material that is capable of transporting, toward the light-emitting layer, electrons injected from the side of the electrode serving as a cathode into the layer including the luminescent material. In addition, it is preferable to form the electron transporting layer 115 with the use of a material that has a larger ionization potential than the material forming the light-emitting layer. However, in the case of providing a hole blocking layer as in the present embodiment mode, it is not always necessary to use a material that has a larger ionization potential than the material forming the light-emitting layer.

[0112]

Specific examples of such a material include metal complexes having a

quinoline skeleton or a benzoquinoline skeleton such as Alq<sub>3</sub>, Gaq<sub>3</sub>, Almq<sub>3</sub>, and bis(10-hydroxybenzo[h]-quinolinato)beryllium (abbreviation: BeBq<sub>2</sub>), and BAq mentioned above. In addition, metal complexes having an oxazole ligand or a thiazole ligand such as bis[2-(2-hydroxyphenyl)-benzoxazolato]zinc (abbreviation: Zn(BOX)<sub>2</sub>) and bis[2-(2-hydroxyphenyl)-benzothiazolato]zinc (abbreviation: Zn(BTZ)<sub>2</sub>) can be also used as a material for forming the electron transporting layer 115. Further, in addition to 2-(4-biphenyl)-5-(4-tert-butylphenyl)-1,3,4-oxadiazole (abbreviation: PBD), and OXD-7, TAZ, p-EtTAZ, BPhen, and BCP mentioned above, inorganic materials such as titanium oxide may be also used.

10 [0113]

The above-described light-emitting element according to the present invention shows less decrease in luminance over light emission time, and shows a favorable lifetime.

[0114]

15 <Embodiment Mode 2>

A light-emitting element according to the present invention will be described with reference to FIG. 2.

The light-emitting element shown in FIG. 2 has a first electrode 201 serving as a cathode on a substrate 200, a layer 202 including a luminescent material on the first electrode 201, and a second electrode 203 serving as an anode on the layer 202 including the luminescent material. As shown in FIG. 2, the layer 202 including the luminescent material is formed by stacking an electron transporting layer 211, a hole blocking layer 212, a light-emitting layer 213, a hole transporting layer 214, and a hole injecting layer 215 in order, where the electron transporting layer 211 and the hole transporting layer 214 are provided on the first electrode 201 side and on the second electrode 203 side, respectively, with the light-emitting layer 216 as a center.

25 [0115]

The electron transporting layer 211, the hole blocking layer 212, the light-emitting layer 213, the hole transporting layer 214, and the hole injecting layer 215 may be formed by evaporation or the like with the use of the same materials as those for the electron transporting layer, the hole blocking layer, the light-emitting layer, the hole transporting layer, and the hole injecting layer described in Embodiment mode 1. As

described above, a light-emitting element in which an electrode to serve as a cathode is provided on a substrate side may be used. It is to be noted that light generated by recombination of carriers in the layer 202 including the luminescent material is emitted from one or both of the first electrode 201 and the second electrode 203 in the light-emitting element according to the present invention.

[0116]

The above-described light-emitting element according to the present invention shows less decrease in luminance over light emission time, and shows a favorable lifetime.

[0117]

<Embodiment Mode 3>

In Embodiment mode 3, a light-emitting element is manufactured over a substrate 300 composed of glass, quartz, a metal, a bulk semiconductor, transparent plastics, a flexible substrate, or the like. By manufacturing a plurality of light-emitting elements over one substrate, a passive matrix light-emitting device can be manufactured. In addition, other than a substrate composed of glass, quartz, transparent plastics, a flexible substrate, or the like, for example, a light-emitting element in contact with a thin film transistor (TFT) array may be manufactured as shown in FIG. 3 where 311 and 312 are TFTs and a light-emitting element 313 according to the present invention is manufactured.

[0118]

For the light-emitting element 313, a first electrode 314, a layer 315 including a luminescent material, and a second electrode 316 can be manufactured. Further, a wiring 317 is manufactured to come in contact with the second electrode 316. In this way, an active matrix light-emitting device where driving of a light-emitting element is controlled by a TFT can be manufactured. It is to be noted that the structures of the TFTs are not particularly limited. For example, a staggered TFT or an inversely staggered TFT may be used. In addition, the degree of crystallinity of a semiconductor layer forming the TFT is not particularly limited either, and may be crystalline or amorphous.

[Embodiments]

[0119]



Based on embodiments, the present invention will be described in more detail below. However, as a matter of course, the present invention is not limited to these embodiments. First, synthesis examples of organometallic complexes will be described, and then, the structures of light-emitting elements according to the present invention and manufacturing methods thereof, and an embodiment of a light-emitting device will be described.

[0120]

«Synthesis Example 1»

The present synthesis example is a synthesis example of bis{2,3-bis(4-fluorophenyl)quinoxalinato}(acetylacetonato)iridium(III) [abbreviation: Ir(Fdpq)<sub>2</sub>(acac)] represented by the structure formula (16).

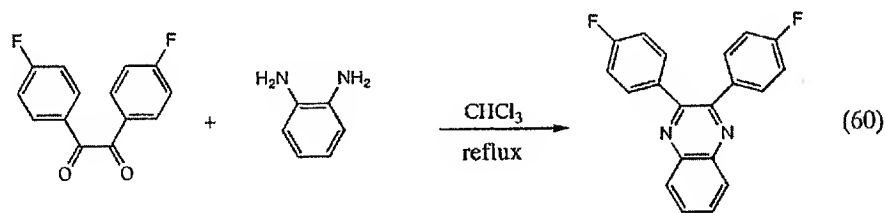
[0121]

<Step 1: Synthesis of Ligand (HFdpq)>

First, 3.71 g of 4,4'-difluorobenzil and 1.71 g of o-phenylenediamine were stirred on heating in a 200 mL chloroform solvent for 6 hours. The reaction solution was cooled to room temperature, washed with 1N HCl and a saturated aqueous solution of sodium chloride, and dried with magnesium sulfate. The solvent was removed to obtain a ligand HFdpq [2,3-bis(4-fluorophenyl)quinoxaline] (pale yellow powder, yield: 99 %). The synthesis scheme and the structure formula of the ligand HFdpq are shown by the following formula (60).

[0122]

[Chemical Formula 54]



[0123]

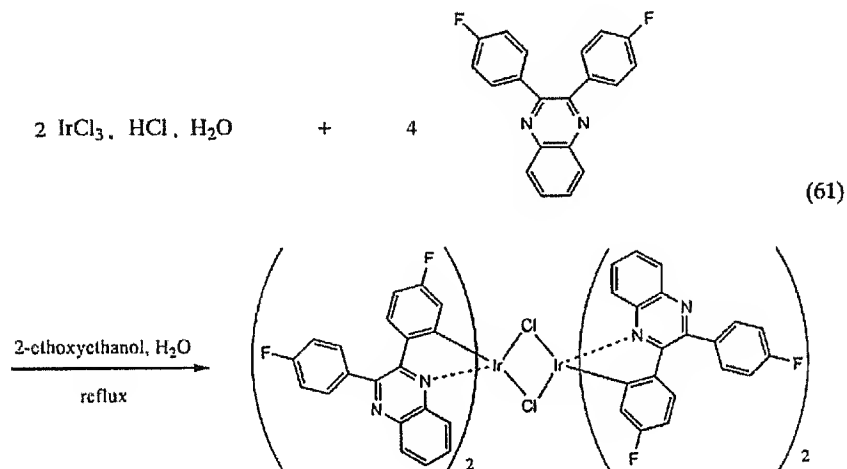
<Step 2: Synthesis of Dinuclear Complex [Ir(Fdpq)<sub>2</sub>Cl]<sub>2</sub>>

With a mixture of 30 ml of 2-ethoxyethanol and 10 ml of water as a solvent, 3.61 g of the ligand HFdpq (2,3-bis(4-fluorophenyl)quinoxaline) and 1.35 g of iridium chloride (IrCl<sub>3</sub> · HCl · H<sub>2</sub>O) were mixed, and held at reflux in a nitrogen atmosphere for

17 hours to obtain a dinuclear complex  $[\text{Ir}(\text{Fdpq})_2\text{Cl}]_2$  (brown powder, yield: 99 %). The synthesis scheme and the structure formula of the dinuclear complex  $[\text{Ir}(\text{Fdpq})_2\text{Cl}]_2$  are shown by the following formula (61).

[0124]

5 [Chemical Formula 55]



[0125]

<Step 3: Synthesis of Organometallic Complex  $\text{Ir}(\text{Fdpq})_2(\text{acac})$  for Light-Emitting Element according to the Present Invention>

10 Further, with 30 ml of 2-ethoxyethanol as a solvent, 2.00 g of the dinuclear complex  $[\text{Ir}(\text{Fdpq})_2\text{Cl}]_2$  obtained in Step 2 described above, 0.44 ml of acetylacetone (Hacac), and 1.23 g of sodium carbonate were mixed, and held at reflux in a nitrogen atmosphere for 20 hours to obtain an organometallic complex  $\text{Ir}(\text{Fdpq})_2(\text{acac})$  represented by the structure formula (16) according to the present invention (red powder,

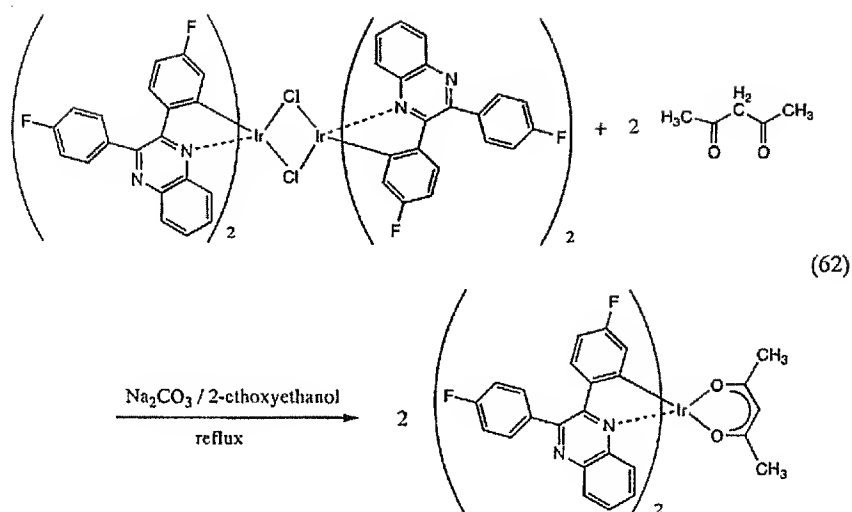
15 yield: 44 %). The synthesis scheme is shown by the following formula (62). The result of analysis of the organometallic complex  $\text{Ir}(\text{Fdpq})_2(\text{acac})$  by nuclear magnetic resonance ( $^1\text{H-NMR}$ ) is as follows.

[0126]

$^1\text{H-NMR}$ .  $\delta(\text{CDCl}_3)$ : 8.20 (d, 2H), 8.11 (d, 2H), 8.01 (brs, 4H), 7.68 (t, 2H),  
 20 7.52 (t, 2H), 7.32 (brm, 4H), 7.08 (m, 2H), 6.39 (td, 2H), 6.05 (dd, 2H), 4.71 (s, 1H),  
 1.62 (s, 6H)

[0127]

[Chemical Formula 56]



[0128]

In addition, measurement of the decomposition temperature  $T_d$  of the obtained  $\text{Ir}(\text{Fdpq})_2(\text{acac})$  was performed by a Thermogravimetry/Differential Thermal Analysis simultaneous measurement system (from Seiko Instruments Inc., TG/DTA-320) to find  
 5  $T_d = 365^\circ\text{C}$ , and thus, it was determined that the organometallic complex  $\text{Ir}(\text{Fdpq})_2(\text{acac})$  shows favorable heat resistance.

[0129]

Further, FIG. 4 shows an absorption spectrum of the obtained  $\text{Ir}(\text{Fdpq})_2(\text{acac})$  in  
 10 dichloromethane and an emission spectrum (Photo Luminescence) thereof. It is to be noted that the emission spectrum was obtained when light with a wavelength of 469 nm, which was extracted by separating light from a halogen lamp with the use of a slit, was used as excitation light. In FIG. 4, the horizontal axis indicates a wavelength (nm), the left vertical axis indicates absorbance (no unit), and the right vertical axis indicates  
 15 emission intensity [arbitrary unit (a.u.)]. As can be seen from FIG. 4, the organometallic complex  $\text{Ir}(\text{Fdpq})_2(\text{acac})$  according to the present invention has absorption peaks at 232 nm, 284 nm, 371 nm, and 472 nm. In addition, the emission spectrum shows luminescence with an emission peak at 644 nm, and this luminescence was viewed as red luminescence.

20 [0130]

In the case of the obtained  $\text{Ir}(\text{Fdpq})_2(\text{acac})$ , the several absorption peaks are observed on the longer wavelength side. This is absorption unique to an

organometallic complex and often observed in the case of an orthometalated complex or the like, and is considered to correspond to singlet MLCT transition, triplet  $\pi$ - $\pi^*$  transition, triplet MLCT (Metal to ligand charge transfer) transition, and the like. In particular, the absorption peak on the longest wavelength side has a broad peak in the visible region, which is considered to be an absorption spectrum unique to triplet MLCT transition. Namely, it was determined that  $\text{Ir}(\text{Fdpq})_2(\text{acac})$  is a compound capable of direct photoexcitation to an excited triplet state and intersystem crossing.

[0131]

In addition, a gas including oxygen was injected into a dichloromethane solution including the obtained  $\text{Ir}(\text{Fdpq})_2(\text{acac})$ , and the emission intensity of  $\text{Ir}(\text{Fdpq})_2(\text{acac})$  was examined when the  $\text{Ir}(\text{Fdpq})_2(\text{acac})$  with dissolved oxygen was made to produce luminescence. Further, argon was injected into a dichloromethane solution including the obtained  $\text{Ir}(\text{Fdpq})_2(\text{acac})$ , and the emission intensity of  $\text{Ir}(\text{Fdpq})_2(\text{acac})$  was examined when the  $\text{Ir}(\text{Fdpq})_2(\text{acac})$  with dissolved argon was made to produce luminescence. From the result, it was determined that luminescence derived from  $\text{Ir}(\text{Fdpq})_2(\text{acac})$  shows the same tendency as luminescence of a phosphorescent material, where the tendency is that the emission intensity is stronger in the case of dissolved argon than dissolved oxygen. Accordingly, luminescence derived from  $\text{Ir}(\text{Fdpq})_2(\text{acac})$  is considered to be phosphorescence.

[0132]

«Synthesis Example 2»

The present synthesis example is a synthesis example of bis(2,3-diphenylquinoxalinato)acetylacetonato iridium(III) (abbreviation:  $\text{Ir}(\text{dpq})_2(\text{acac})$ ) represented by the structure formula (17).

[0133]

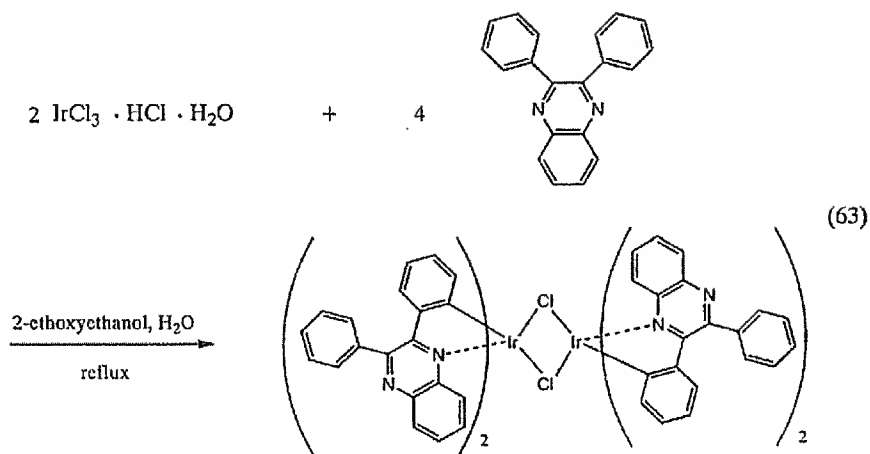
<Step 1: Synthesis of Dinuclear Complex  $[\text{Ir}(\text{dpq})_2\text{Cl}]_2$ >

First, with a mixture of 30 ml of 2-ethoxyethanol and 10 ml of water as a solvent, 2.36 g of a ligand Hdpq (2,3-diphenylquinoxaline) and 1.00 g of iridium chloride ( $\text{IrCl}_3 \cdot \text{HCl} \cdot \text{H}_2\text{O}$ ) were mixed, and held at reflux in a nitrogen atmosphere for 15 hours to obtain a dinuclear complex  $[\text{Ir}(\text{dpq})_2\text{Cl}]_2$  (dark brown powder, yield: 91 %). The synthesis scheme and the structure formula of the dinuclear complex  $[\text{Ir}(\text{dpq})_2\text{Cl}]_2$

are shown by the following formula (63).

[0134]

[Chemical Formula 57]



5 [0135]

<Step 2: Synthesis of Organometallic Complex  $\text{Ir}(\text{dpq})_2(\text{acac})$  according to the Present Invention>

Further, with 30 ml of 2-ethoxyethanol as a solvent, 1.00 g of  $[\text{Ir}(\text{dpq})_2\text{Cl}]_2$  obtained in Step 1 described above, 0.20 ml of acetylacetone (Hacac), and 0.67 g of sodium carbonate were mixed, and held at reflux in a nitrogen atmosphere for 15 hours. This was filtered, and the obtained solution was purified by column chromatography with the use of a dichloromethane solvent. Recrystallization was performed with the use of a dichloromethane/methanol solvent to obtain an organometallic complex  $\text{Ir}(\text{dpq})_2(\text{acac})$  according to the present invention (reddish brown powder, yield: 40 %).

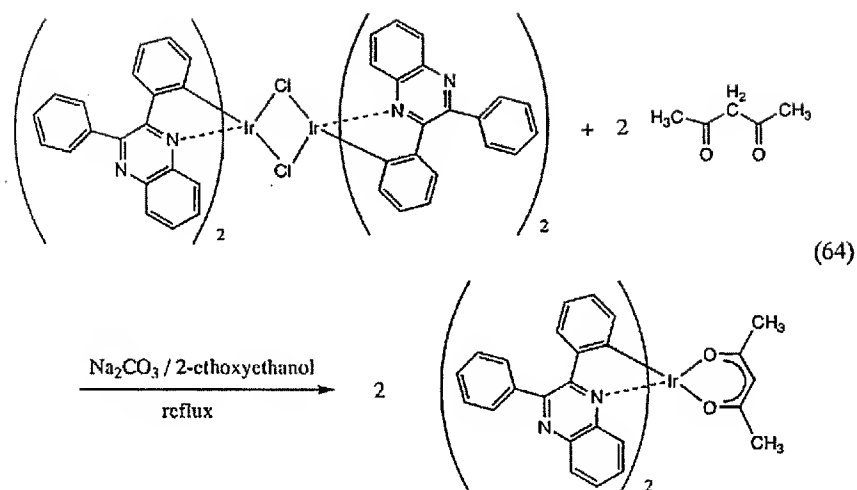
15 The synthesis scheme is shown by the following formula (64). The result of analysis of the present organometallic complex  $\text{Ir}(\text{dpq})_2(\text{acac})$  by nuclear magnetic resonance ( $^1\text{H}$ -NMR) is as follows.

[0136]

$^1\text{H}$ -NMR.  $\delta$  ( $\text{CDCl}_3$ ): 8.15 (t, 4H), 7.89 (brs, 4H), 7.79 (t, 2H), 7.69 (m, 8H), 6.94 (d, 2H), 6.57 (t, 2H), 6.48 (t, 2H), 6.33 (d, 2H), 4.81 (s, 1H), 1.64 (s, 6H)

[0137]

[Chemical Formula 58]



[0138]

In addition, measurement of the decomposition temperature  $T_d$  of the obtained  $\text{Ir}(\text{dpq})_2(\text{acac})$  was performed by a Thermogravimetry/Differential Thermal Analysis simultaneous measurement system (from Seiko Instruments Inc., TG/DTA-320) to find  $T_d = 340\text{ }^\circ\text{C}$ , and thus, it was determined that the organometallic complex  $\text{Ir}(\text{dpq})_2(\text{acac})$  shows favorable heat resistance.

[0139]

Further, FIG. 5 shows an absorption spectrum of the obtained  $\text{Ir}(\text{dpq})_2(\text{acac})$  in dichloromethane and an emission spectrum (PL) thereof. It is to be noted that the emission spectrum was obtained when light with a wavelength of 469 nm, which was extracted by separating light from a halogen lamp with the use of a slit, was used as excitation light. In FIG. 5, the horizontal axis indicates a wavelength (nm), the left vertical axis indicates absorbance (no unit), and the right vertical axis indicates emission intensity (a.u.). As can be seen from FIG. 5, the obtained organometallic complex  $\text{Ir}(\text{dpq})_2(\text{acac})$  has absorption peaks at 248 nm, 283 nm, 378 nm, and 479 nm. In addition, the emission spectrum shows luminescence with an emission peak at 687 nm, and this luminescence was viewed as deep red luminescence.

[0140]

In the case of the obtained  $\text{Ir}(\text{dpq})_2(\text{acac})$ , the several absorption peaks are observed on the longer wavelength side. This is absorption unique to an organometallic complex and often observe in the case of an orthometalated complex or

the like, and is considered to correspond to singlet MLCT transition, triplet  $\pi$ - $\pi^*$  transition, triplet MLCT transition, and the like. In particular, the absorption peak on the longest wavelength side has a broad peak in the visible region, which is considered to be an absorption spectrum unique to triplet MLCT transition. Namely, it was  
5 determined that Ir(dpq)<sub>2</sub>(acac) is a compound capable of direct photoexcitation to an excited triplet state and intersystem crossing.

[0141]

In addition, a gas including oxygen was injected into a dichloromethane solution including the obtained Ir(dpq)<sub>2</sub>(acac), and the emission intensity of  
10 Ir(dpq)<sub>2</sub>(acac) was examined when the Ir(dpq)<sub>2</sub>(acac) with dissolved oxygen was made to produce luminescence. Further, argon was injected into a dichloromethane solution including the obtained Ir(dpq)<sub>2</sub>(acac), and the emission intensity of Ir(dpq)<sub>2</sub>(acac) was examined when the Ir(dpq)<sub>2</sub>(acac) with dissolved argon was made to produce luminescence. From the result, it was determined that luminescence derived from  
15 Ir(dpq)<sub>2</sub>(acac) shows the same tendency as luminescence of a phosphorescent material, where the tendency is that the emission intensity is stronger in the case of dissolved argon than dissolved oxygen. Accordingly, luminescence derived from Ir(dpq)<sub>2</sub>(acac) is considered to be phosphorescence.

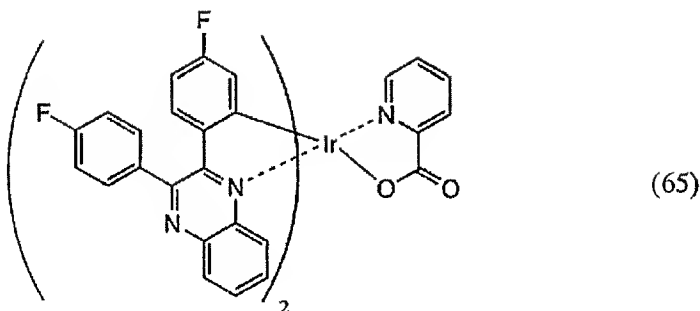
[0142]

20 «Synthesis Example 3»

The present synthesis example is a synthesis example of bis{2,3-bis(4-fluorophenyl)quinoxalinato}picolinato iridium(III) [abbreviation: Ir(Fdpq)<sub>2</sub>(pic)] included in the following general formulas (1) ~ (8). The structure formula of Ir(Fdpq)<sub>2</sub>(pic) is shown by the following formula (65).

25 [0143]

30 [Chemical Formula 59]



[0144]

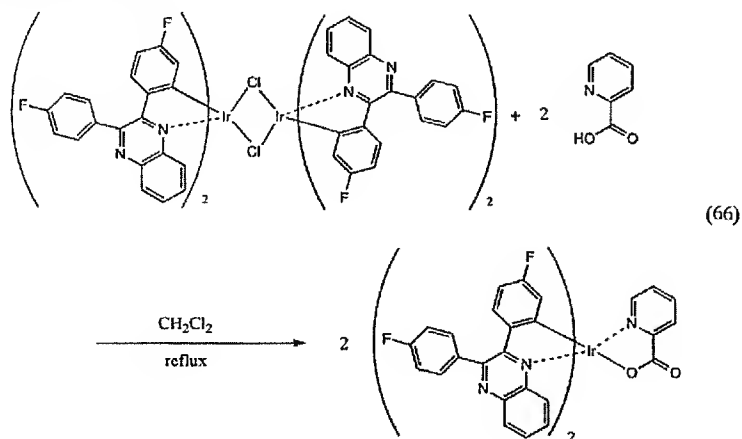
First, the dinuclear complex  $[\text{Ir}(\text{Fdpq})_2\text{Cl}]_2$  obtained in Step 2 of Synthesis Example 1 was used as a material. With 30 ml of dichloromethane as a solvent, 2.87 g of  $[\text{Ir}(\text{Fdpq})_2\text{Cl}]_2$  and 1.67 g of picolinic acid (Hpic) were mixed, and held at reflux in a nitrogen atmosphere for 16 hours. This was filtered to obtain an organometallic complex  $\text{Ir}(\text{Fdpq})_2(\text{pic})$  according to the present invention (red powder, yield: 56 %). The synthesis scheme is shown by the following formula (66). The result of analysis of the present organometallic complex  $\text{Ir}(\text{Fdpq})_2(\text{pic})$  by nuclear magnetic resonance ( $^1\text{H-NMR}$ ) is as follows.

[0145]

$^1\text{H-NMR}$ .  $\delta(\text{CDCl}_3)$ : 8.66 (d, 1H), 8.45 (d, 1H), 8.04 (m, 4H), 7.95 (d, 1H), 7.81 (m, 3H), 7.69 (m, 2H), 7.59 (t, 1H), 7.53 (t, 1H), 7.33 (m, 5H), 7.18 (t, 1H), 7.07 (t, 2H), 6.51 (td, 1H), 6.38 (m, 2H), 5.78 (dd, 1H)

15 [0146]

[Chemical Formula 60]



[0147]



In addition, measurement of the decomposition temperature  $T_d$  of the obtained  $\text{Ir}(\text{Fdpq})_2(\text{acac})$  was performed by a Thermogravimetry/Differential Thermal Analysis simultaneous measurement system (from Seiko Instruments Inc., TG/DTA-320) to find  $T_d = 347\text{ }^\circ\text{C}$ , and thus, it was determined that the organometallic complex  $\text{Ir}(\text{Fdpq})_2(\text{pic})$  shows favorable heat resistance.

[0148]

Further, FIG. 6 shows an absorption spectrum of the obtained  $\text{Ir}(\text{Fdpq})_2(\text{pic})$  in dichloromethane and an emission spectrum (PL) thereof. It is to be noted that the emission spectrum was obtained when light with a wavelength of 468 nm, which was extracted by separating light from a halogen lamp with the use of a slit, was used as excitation light. In FIG. 6, the horizontal axis indicates a wavelength (nm), the left vertical axis indicates absorbance (no unit), and the right vertical axis indicates emission intensity (arbitrary unit). As can be seen from FIG. 6, the obtained organometallic complex  $\text{Ir}(\text{Fdpq})_2(\text{pic})$  has a plurality of absorption peaks. In addition, the emission spectrum shows luminescence with an emission peak at 625 nm, and this luminescence was viewed as red luminescence.

[0149]

The absorption peak on the longest wavelength side has a broad peak in the visible region, which is considered to be an absorption spectrum unique to triplet MLCT transition. Namely, it is determined that  $\text{Ir}(\text{Fdpq})_2(\text{pic})$  is a compound capable of direct photoexcitation to an excited triplet state and intersystem crossing.

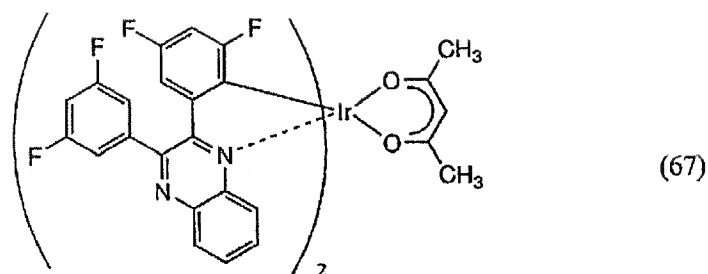
[0150]

«Synthesis Example 4»

In the present synthesis example, synthesis of bis{2,3-bis(3,5-difluorophenyl)quinoxalinato}acetylacetonato iridium(III) [abbreviation:  $\text{Ir}(3,5\text{-Fdpq})_2(\text{acac})$ ] included in the following general formulas (1) ~ (8) will be described. The structure formula of  $\text{Ir}(3,5\text{-Fdpq})_2(\text{acac})$  is shown by (67).

[0151]

[Chemical Formula 61]



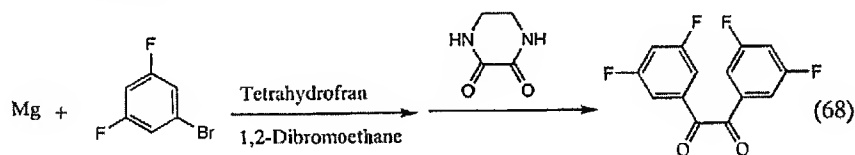
[0152]

<Step 1: Synthesis of 3,3',5,5'-tetrafluorobenzyl>

3,3', 5, 5' - tetrafluorobenzyl that is a material for a ligand was synthesized as follows. First, 3.16 g of magnesium was suspended in 3 ml of tetrahydrofuran (abbreviation: THF), and a small amount of 1,2-dibromoethane was added. Into this mixture, a solution obtained by adding 25.00 g of 1-bromo-3,5-difluorobenzene into 130 ml of THF was dropped, and stirring was performed for 1.5 hours while holding at reflux on heating. Next, 9.24 g of 1,4-dimethylpiperazine-2,3-dione was added to the solution cooled to room temperature, and stirring was performed for 13 hours while holding at reflux on heating. Further, 200 ml of 10 % hydrochloric acid was added to the solution cooled to room temperature, and the organic layer was extracted with chloroform. After drying with sodium sulfate, the solvent was condensed. Finally, purification was performed by column chromatography (hexane/dichloromethane system) to obtain 3,3',5,5'-tetrafluorobenzyl (yellow powder, yield: 46 %). The synthesis scheme is shown by the following formula (68).

[0153]

[Chemical Formula 62]



20 [0154]

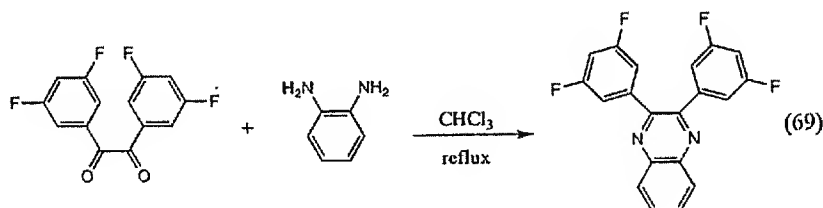
<Step 2: Synthesis of ligand H(3,5-Fdpq)>

300 ml of chloroform was added to 8.32 g of 3,3',5,5'-tetrafluorobenzyl synthesized in Step 1 and 3.19 g of 1,2-phenylenediamine, and stirring was performed for 10 hours while holding at reflux on heating. The solution cooled to room

temperature was washed with 1N hydrochloric acid and then a saturated aqueous solution of sodium chloride, and dried with magnesium sulfate. Then, the solvent was condensed to obtain 2,3-bis(3,5-difluorophenyl)quinoxaline (ligand H(3,5-Fdpq)) (white powder, yield: 98 %). The synthesis scheme and the structure formula of the ligand H(3,5-Fdpq) are shown by the following formula (69).

[0155]

[Chemical Formula 63]



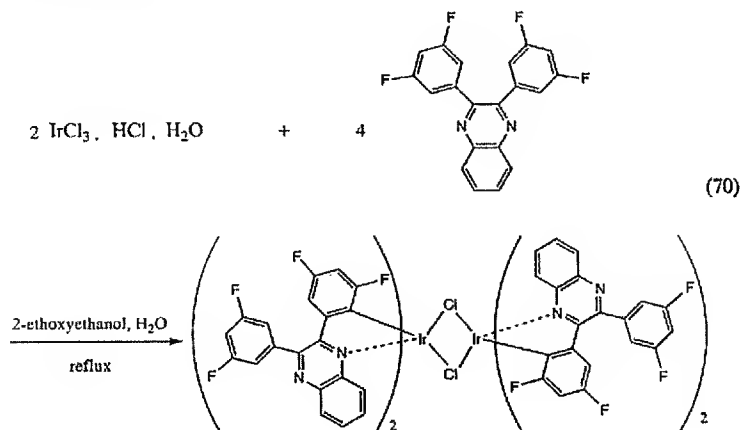
[0156]

#### 10 <Step 3: Synthesis of Dinuclear Complex [Ir(3,5-Fdpq)<sub>2</sub>Cl]<sub>2</sub>>

First, with a mixture of 30 ml of 2-ethoxyethanol and 10 ml of water as a solvent, 2.46 g of the ligand H(3,5-Fdpq) synthesized in Step 2 and 0.83 g of iridium chloride (IrCl<sub>3</sub>·HCl·H<sub>2</sub>O) were mixed, and held at reflux in a nitrogen atmosphere for 17 hours to obtain a dinuclear complex [Ir(3,5-Fdpq)<sub>2</sub>Cl]<sub>2</sub> (reddish brown powder, yield: 78 %). The synthesis scheme and the structure formula of the dinuclear complex [Ir(3,5-Fdpq)<sub>2</sub>Cl]<sub>2</sub> are shown by the following formula (70).

[0157]

[Chemical Formula 64]



20 [0158]

<Step 3: Synthesis of Organometallic Complex Ir(3,5-Fdpq)<sub>2</sub>(acac)>

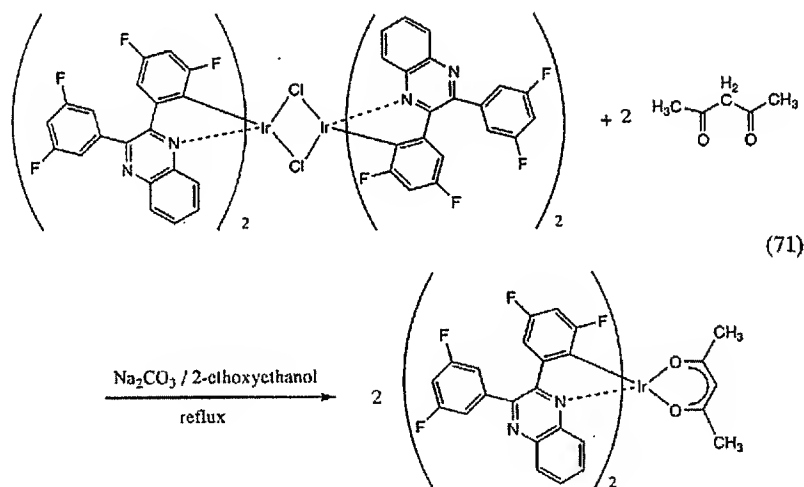
With 30 ml of 2-ethoxyethanol as a solvent, 2.34 g of the dinuclear complex [Ir(3,5-Fdpq)<sub>2</sub>Cl]<sub>2</sub> obtained in Step 3 described above, 0.39 ml of acetylacetone (Hacac), and 1.32 g of sodium carbonate were mixed, and held at reflux in a nitrogen atmosphere for 20 hours to obtain an organometallic complex Ir(3,5-Fdpq)<sub>2</sub>(acac) represented by the formula (67) according to the present invention (dark red powder, yield: 22 %). The synthesis scheme is shown by the following formula (71). The result of analysis of the present organometallic complex Ir(3,5-Fdpq)<sub>2</sub>(acac) by nuclear magnetic resonance (<sup>1</sup>H-NMR) is as follows.

[0159]

<sup>1</sup>H-NMR. δ(CDCl<sub>3</sub>): 8.10 (t, 4H), 7.75 (t, 2H), 7.61 (m, 4H), 7.30 (m, 2H), 7.09 (tt, 2H), 6.77 (dd, 2H), 6.20 (td, 2H), 4.67 (s, 1H), 1.61 (s, 6H)

[0160]

[Chemical Formula 65]



[0161]

In addition, measurement of the decomposition temperature  $T_d$  of the obtained Ir(3,5-Fdpq)<sub>2</sub>(acac) was performed by a Thermogravimetry/Differential Thermal Analysis simultaneous measurement system (from Seiko Instruments Inc., TG/DTA-320) to find  $T_d = 342\text{ }^{\circ}\text{C}$ , and thus, it was determined that the organometallic complex Ir(3,5-Fdpq)<sub>2</sub>(acac) shows favorable heat resistance.

[0162]

Further, FIG. 7 shows an absorption spectrum of the obtained Ir(3,5-Fdpq)<sub>2</sub>(acac) in dichloromethane and an emission spectrum (PL) thereof. It is to be noted that the emission spectrum was obtained when light with a wavelength of 468 nm, which was extracted by separating light from a halogen lamp with the use of a slit, was used as excitation light. In FIG. 7, the horizontal axis indicates a wavelength (nm), the left vertical axis indicates absorbance (no unit), and the right vertical axis indicates emission intensity (arbitrary unit). As can be seen from FIG. 7, the obtained organometallic complex Ir(3,5-Fdpq)<sub>2</sub>(acac) has a plurality of absorption peaks. In addition, the emission spectrum shows luminescence with an emission peak at 666 nm, and this luminescence was viewed as deep red luminescence.

[0163]

The absorption peak on the longest wavelength side has a broad shape in the visible region, which is considered to be an absorption spectrum unique to triplet MLCT transition. Namely, it was determined that Ir(3,5-Fdpq)<sub>2</sub>(acac) is a compound capable of direct photoexcitation to an excited triplet state and intersystem crossing.

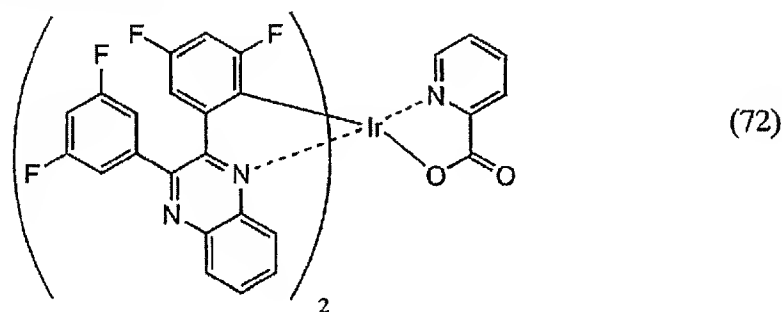
[0164]

#### «Synthesis Example 5»

In the present synthesis example, synthesis of bis{2,3-bis(3,5-difluorophenyl)quinoxalinato}picolinato iridium(III) [abbreviation: Ir(3,5-Fdpq)<sub>2</sub>(pic)] included in the following general formulas (1) ~ (8) will be described. The structure formula of Ir(3,5-Fdpq)<sub>2</sub>(pic) is shown by the following formula (72).

[0165]

[Chemical Formula 66]



25

[0166]

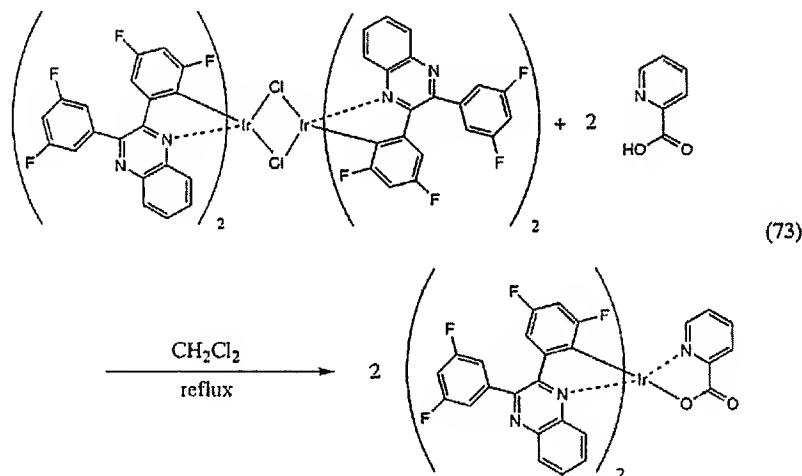
With 30 ml of dichloromethane as a solvent, 2.54 g of the dinuclear complex  $[\text{Ir}(3,5\text{-Fdpq})_2\text{Cl}]_2$  synthesized in Step 3 of Synthesis Example 4 and 1.34 g of picolinic acid (Hpic) were mixed, and held at reflux in a nitrogen atmosphere for 16 hours. This was filtered to obtain an organometallic complex  $\text{Ir}(3,5\text{-Fdpq})_2(\text{pic})$  according to the present invention (red powder, yield: 14 %). The synthesis scheme is shown by the following formula (73). The result of analysis of the present organometallic complex  $\text{Ir}(3,5\text{-Fdpq})_2(\text{pic})$  by nuclear magnetic resonance ( $^1\text{H-NMR}$ ) is as follows.

[0167]

$^1\text{H-NMR}$ .  $\delta(\text{CDCl}_3)$ : 8.65 (d, 1H), 8.54 (d, 1H), 8.06 (m, 2H), 7.87-7.54 (m, 8H), 7.32 (m, 3H), 7.12 (m, 3H), 6.85 (d, 1H), 6.74 (d, 1H), 6.37 (t, 1H), 6.17 (t, 1H)

[0168]

[Chemical Formula 67]



[0169]

In addition, measurement of the decomposition temperature  $T_d$  of the obtained  $\text{Ir}(3,5\text{-Fdpq})_2(\text{pic})$  was performed by a Thermogravimetry/Differential Thermal Analysis simultaneous measurement system (from Seiko Instruments Inc., TG/DTA-320) to find  $T_d = 347\text{ }^\circ\text{C}$ , and thus, it was determined that the organometallic complex  $\text{Ir}(3,5\text{-Fdpq})_2(\text{pic})$  shows favorable heat resistance.

[0170]

Further, FIG. 8 shows an absorption spectrum of the obtained  $\text{Ir}(3,5\text{-Fdpq})_2(\text{pic})$  in dichloromethane and an emission spectrum (PL) thereof. It is to be noted that the

emission spectrum was obtained when light with a wavelength of 468 nm, which was extracted by separating light from a halogen lamp with the use of a slit, was used as excitation light. In FIG. 8, the horizontal axis indicates a wavelength (nm), the left vertical axis indicates absorbance (no unit), and the right vertical axis indicates emission intensity (arbitrary unit). As can be seen from FIG. 8, the obtained organometallic complex  $\text{Ir}(3,5\text{-Fdpq})_2(\text{pic})$  has a plurality of absorption peaks. In addition, the emission spectrum shows luminescence with an emission peak at 645 nm, and this luminescence was viewed as red luminescence.

[0171]

The absorption peak on the longest wavelength side has a broad peak in the visible region, which is considered to be an absorption spectrum unique to triplet MLCT transition. Namely, it was determined that  $\text{Ir}(3,5\text{-Fdpq})_2(\text{pic})$  is a compound capable of direct photoexcitation to an excited triplet state and intersystem crossing.

[0172]

The organometallic complexes described in Synthesis Examples 1 ~ 5 according to the present invention can be used as a luminescent material or a photosensitizer.

[0173]

«Embodiment 1»

In the present embodiment, the structure of a light-emitting element according to the present invention and a manufacturing method thereof will be described with reference to FIG. 9.

[0174]

First, on a substrate 400, a first electrode 401 was formed by deposition of indium tin oxide so as to be 110 nm in film thickness. It is to be noted that sputtering was used for the deposition.

[0175]

Next, on the first electrode 401, a hole injecting layer 411 was formed by deposition of copper phthalocyanine so as to be 20 nm in film thickness. The deposition was performed by evaporation using resistance heating in such a way that the substrate on which the first electrode 401 was formed was fixed to a substrate holder of

a commercially produced vacuum deposition system with the surface on which the first electrode 401 was formed set on the lower side and copper phthalocyanine was put in an evaporation source provided in the vacuum deposition system.

[0176]

5           Next, on the hole injecting layer 411, a hole transporting layer 412 was formed by deposition of  $\alpha$ -NPD so as to be 40 nm in film thickness. The deposition was performed by evaporation in a similar way to the formation of the hole injecting layer 411.

[0177]

10           Next, a light-emitting layer 413 was formed by deposition of  $\alpha$ -NPD so that bis{2,3-bis(4-fluorophenyl)quinoxalinato}acetylacetonato iridium(III) [hereinafter, referred to as Ir(Fdpq)<sub>2</sub>(acac)] represented by the structure formula (16) is included at a rate of 8 weight% in  $\alpha$ -NPD. The deposition was performed by co-evaporation with  $\alpha$ -NPD and Ir(Fdpq)<sub>2</sub>(acac) as evaporation sources so that the film thickness is 30 nm.

15           Here,  $\alpha$ -NPD functions as a host material.

[0178]

          Next, on the light-emitting layer 413, an electron transporting layer 414 was formed by deposition of Alq<sub>3</sub> so as to be 30 nm in film thickness. The deposition was performed by evaporation in a similar way to the formation of the hole injecting layer  
20           411. Then, on the electron transporting layer 414, an electron injecting layer 415 was formed by deposition of calcium fluoride (CaF<sub>2</sub>) so as to be 1 nm in film thickness. The deposition was performed by evaporation in a similar way to the formation of the hole injecting layer 411.

[0179]

25           In this way, a layer including a luminescent material 402 was formed by stacking the hole injecting layer 411, the hole transporting layer 412, the light-emitting layer 413, the electron transporting layer 414, and the electron injecting layer 415.

[0180]

          Next, on the electron injecting layer 415, a second electrode 403 was formed  
30           by deposition of aluminum so as to be 150 nm in film thickness. The deposition was performed by evaporation in a similar way to the formation of the hole injecting layer



411.

[0181]

Further, the manufactured light-emitting element was moved into a glove box in a nitrogen atmosphere, and sealing was performed with the use of a sealing material in the glove box. After sealing of the light-emitting element, the light-emitting element was taken out from the glove box, and current density-luminance characteristics, voltage-luminance characteristics, and luminance-current efficiency characteristics in an initial condition were examined at room temperature (about 25 °C). In addition, a continuous lighting test by constant current driving was performed to examine the lifetime of the element.

[0182]

First, FIG. 10 shows initial characteristics of the manufactured light-emitting element. FIG. 9(a) shows current density-luminance characteristics, FIG. 10(b) shows voltage-luminance characteristics, and FIG. 10(c) shows luminance-current efficiency characteristics. From the voltage-luminance characteristics, it was determined that light was emitted with a luminance of 440 cd/m<sup>2</sup> when a voltage of 9.0 V was applied, and that the emission efficiency was 1.0 cd/A in that case. Further, the emission spectrum has a peak at a wavelength of 647 nm, and the element exhibits CIE chromaticity coordinates of (x, y) = (0.67, 0.32), from which it was determined that red or reddish luminescence with quite high color purity is provided due to Ir(Fdpq)<sub>2</sub>(acac).

[0183]

Next, the continuous lighting test was performed by constant current driving in which a current with a constant current value is applied for a certain period of time. As a test method, a current of a current density (44.3 mA/cm<sup>2</sup>) required for enabling light emission with a luminance of 440 cd/m<sup>2</sup> in the initial condition was kept applied for a certain period of time to examine change in luminance with time. In the result, the luminance after a lapse of 3800 hours was kept at 68 % of the luminance in the initial condition without reducing by half. From this result, it was determined that reduction in luminance with time of the light-emitting element according to the present invention is small, and the light-emitting element has a favorable lifetime.

[0184]

«Embodiment 2»

In the present embodiment, the structure of a light-emitting element using Alq<sub>3</sub> as a host material according to the present invention and a manufacturing method thereof will be described with reference to FIG. 11.

5 [0185]

First, on a substrate 500, a first electrode 501 was formed by deposition of indium tin oxide so as to be 110 nm in film thickness. It is to be noted that sputtering was used for the deposition.

[0186]

10 Next, on the first electrode 501, a hole injecting layer 511 was formed by deposition of DNTPD so as to be 20 nm in film thickness. The deposition was performed by evaporation using resistance heating in such a way that the substrate on which the first electrode 501 was formed was fixed to a substrate holder of a commercially produced vacuum deposition system with the surface on which the first  
15 electrode 501 was formed set on the lower side and DNTPD was put in an evaporation source provided in the vacuum deposition system.

[0187]

Next, on the hole injecting layer 511, a hole transporting layer 512 was formed by deposition of  $\alpha$ -NPD so as to be 10 nm in film thickness. The deposition was  
20 performed by evaporation in a similar way to the formation of the hole injecting layer 511.

[0188]

Next, a light-emitting layer 513 was formed by deposition of Alq<sub>3</sub> so that bis{2,3-bis(4-fluorophenyl)quinoxalinato}acetylacetonato) iridium(III) (hereinafter,  
25 referred to as Ir(Fdpq)<sub>2</sub>(acac)) represented by the structure formula (16) is included at a rate of 8 weight% in Alq<sub>3</sub>. The deposition was performed by co-evaporation of Alq<sub>3</sub> and Ir(Fdpq)<sub>2</sub>(acac) as evaporation sources so that the film thickness is 30 nm. Here, Alq<sub>3</sub> functions as a host material.

[0189]

30 Next, on the light-emitting layer 513, an electron transporting layer 514 was formed by deposition of Alq<sub>3</sub> so as to be 30 nm in film thickness. The deposition was

performed by evaporation in a similar way to the formation of the hole injecting layer 511.

[0190]

5       Next, on the electron transporting layer 514, an electron injecting layer 515 was formed by deposition of calcium fluoride ( $\text{CaF}_2$ ) so as to be 1 nm in film thickness. The deposition was performed by evaporation in a similar way to the formation of the hole injecting layer 511.

[0191]

10       In this way, a layer including a luminescent material 502 was formed by stacking the hole injecting layer 511, the hole transporting layer 512, the light-emitting layer 513, the electron transporting layer 514, and the electron injecting layer 515.

[0192]

15       Next, on the electron injecting layer 515, a second electrode 503 was formed by deposition of aluminum so as to be 150 nm in film thickness. The deposition was performed by evaporation in a similar way to the formation of the hole injecting layer 511.

[0193]

20       Further, the manufactured light-emitting element was moved into a glove box in a nitrogen atmosphere, and sealing was performed with the use of a sealing material in the glove box. After sealing of the light-emitting element, the light-emitting element was taken out from the glove box, and current density-luminance characteristics, voltage-luminance characteristics, and luminance-current efficiency characteristics in an initial condition were examined at room temperature (about 25 °C). In addition, a continuous lighting test by constant current driving was performed to examine the  
25       lifetime of the element.

[0194]

30       First, FIG. 12 shows initial characteristics of the manufactured light-emitting element. FIG. 12(a) shows current density-luminance characteristics, FIG. 12(b) shows voltage-luminance characteristics, and FIG. 12(c) shows luminance-current efficiency characteristics. From the voltage-luminance characteristics, it was determined that light was emitted with a luminance of 470  $\text{cd/m}^2$  when a voltage of 10.6 V was applied, and that the emission efficiency was 1.1  $\text{cd/A}$  in that case. Further, the emission

spectrum has a peak at a wavelength of 659 nm, and the element exhibits CIE chromaticity coordinates of  $(x, y) = (0.70, 0.30)$ , from which it was determined that red or reddish luminescence with quite high color purity is provided due to  $\text{Ir}(\text{Fdpq})_2(\text{acac})$ .  
[0195]

5           Next, the continuous lighting test by constant current driving was performed. As a test method, a current of a current density ( $41.7 \text{ mA/cm}^2$ ) required for enabling light emission with a luminance of  $470 \text{ cd/m}^2$  in the initial condition was kept applied for a certain period of time to examine change in luminance with time. In the result, the luminance after a lapse of 1400 hours was kept at 89 % of the luminance in the  
10   initial condition without reducing by half. From this result, it was determined that reduction in luminance with time of the light-emitting element according to the present invention is small, and the light-emitting element has a favorable lifetime.  
[0196]

«Embodiment 3»

15           In the present embodiment, an example of a light-emitting element using two kinds of materials,  $\alpha$ -NPD and  $\text{Alq}_3$ , as host materials will be described. The element in the present embodiment was manufactured in a similar way to that in Embodiment 2 except the structure of the light-emitting layer 513 as described below.  
[0197]

20           The light-emitting layer 513 was formed by three-source evaporation in which  $\text{Ir}(\text{Fdpq})_2(\text{acac})$  represented by the structure formula (16) was evaporated while setting the evaporation rate of  $\alpha$ -NPD at  $0.4 \text{ nm/s}$  and setting the evaporation rate of  $\text{Alq}_3$  at  $0.1 \text{ nm/s}$ . In this case, the addition amount of  $\text{Ir}(\text{Fdpq})_2(\text{acac})$  was controlled so as to be 8 weight% with respect to  $\alpha$ -NPD. In addition, the film thickness was made to be 30 nm.  
25   Here,  $\alpha$ -NPD and  $\text{Alq}_3$  function as host materials.  
[0198]

          Further, the manufactured light-emitting element was moved into a glove box in a nitrogen atmosphere, and sealing was performed with the use of a sealing material in the glove box. After sealing of the light-emitting element, the light-emitting  
30   element was taken out from the glove box, and current density-luminance characteristics, voltage-luminance characteristics, and luminance-current efficiency characteristics in an

initial condition were examined at room temperature (about 25 °C). In addition, a continuous lighting test by constant current driving was performed to examine the lifetime of the element.

[0199]

5 First, FIG. 13 shows initial characteristics of the manufactured light-emitting element. FIG. 13(a) shows current density-luminance characteristics, FIG. 13(b) shows voltage-luminance characteristics, and FIG. 13(c) shows luminance-current efficiency characteristics. From the result, it was determined that light was emitted with a luminance of 510 cd/m<sup>2</sup> when a voltage of 7.6 V was applied, and that the emission  
10 efficiency was 1.3 cd/A in that case. Further, the emission spectrum has a peak at a wavelength of 640 nm, and the element exhibits CIE chromaticity coordinates of (x, y) = (0.70, 0.30), from which it was determined that red or reddish luminescence with quite high color purity is provided due to Ir(Fdpq)<sub>2</sub>(acac).

[0200]

15 Next, the continuous lighting test by constant current driving was performed. As a test method, a current of a current density (37.8 mA/cm<sup>2</sup>) required for enabling light emission with a luminance of 510 cd/m<sup>2</sup> in the initial condition was kept applied for a certain period of time to examine change in luminance with time. In the result, the luminance after a lapse of 1200 hours was kept at 90 % of the luminance in the  
20 initial condition without reducing by half. From this result, it was determined that reduction in luminance with time of the light-emitting element according to the present invention is small, and the light-emitting element has a favorable lifetime.

[0201]

«Embodiment 4»

25 In Embodiment 4, a light-emitting device that has a light-emitting element according to the present invention in a pixel portion will be described with reference to FIG. 14. FIG. 14(A) is a top view showing the light-emitting device and FIG. 14(B) is a cross-sectional view along A-A' in FIG. 14(A) (a cross-sectional view taken along A-A'). Reference numeral 601 indicated by a dotted line denotes a driver circuit  
30 portion (a source side driver circuit), reference numeral 602 denotes a pixel portion, and reference numeral 603 denotes a driver circuit portion (a gate side driver circuit). In

addition, reference numerals 604 and 605 denote a sealing substrate and a sealing material, respectively. An inside 607 surrounded by the sealing material 605 is a space.

[0202]

5           Further, reference numeral 608 denotes a wiring for transmitting signals to be input to the source side driver circuit 601 and the gate side driver circuit 603, and receives signals such as a video signal, a clock signal, a start signal, and a reset signal from an FPC (Flexible Printed Circuit) 709 that serves as an external input terminal. It is to be noted that although only the FPC is shown in the FIGure here, a printed wiring  
10   board (PWB) may be attached to this FPC. The light-emitting device according to the present invention may include not only a light-emitting device body but also a state in which an FPC or a PWB is attached thereto.

[0203]

          Next, the cross-sectional structure will be explained with reference to FIG.  
15   14(B). Although the driver circuits and the pixel portion are formed over a substrate 610, the source side driver circuit 601 as the driver circuit portion and the pixel portion 602 are shown here.

[0204]

          In the source side driver circuit 601, a CMOS circuit is formed by a  
20   combination of an n-channel TFT 623 and a p-channel TFT 624. The TFTs forming the driver circuit may be formed by a known CMOS circuit, PMOS circuit, or NMOS circuit. Although the present embodiment shows a driver integrated type in which a driver circuit is formed over a substrate, which is not always necessary, the driver circuit can be formed not over the substrate but outside the substrate.

25   [0205]

          The pixel portion 602 has a plurality of pixels, including a switching TFT 611, a current controlling TFT 612, and a first electrode 613 electrically connected to a drain of the current controlling TFT 612. In addition, an insulator 614 is formed to cover an edge of the first electrode 613. Here, a positive photosensitive acrylic resin film is  
30   used to form the insulator 614.

[0206]

          Besides, in order to obtain a favorable coverage, the insulator 614 is formed to

have a top portion or a bottom portion with a curved surface that has a curvature. For example, in the case of using positive photosensitive acrylic as a material for the insulator 614, it is preferable that only a top portion of the insulator 614 have a curved surface with a curvature radius ( $0.2\ \mu\text{m} \sim 3\ \mu\text{m}$ ). In addition, any of a negative photosensitive material that becomes insoluble in an etchant by light and a positive photosensitive material that becomes soluble in an etchant by light can be used for the insulator 614. Further, it is possible to use not only organic substances but also inorganic substances as a material for the insulator 614, for example, silicon oxide, silicon oxynitride, or the like can be used.

10 [0207]

On the first electrode 613, a layer 616 including a luminescent material and a second electrode 617 are formed. Here, as a material to be used for the first electrode 613 that functions as an anode, it is preferable to use a material that has a large work function. For example, in addition to single layers such as a film including indium tin oxide, a film including indium tin oxide containing silicon oxide, a film including indium zinc oxide, a titanium nitride film, a chromium film, a tungsten film, a Zn film, and a Pt film, laminated structures such as a laminate of a titanium nitride film and a film including aluminum as its main component and a three-layer structure of a titanium nitride film, a film including aluminum as its main component, and a titanium nitride film can be used. When a laminated structure is used, it can have a lower resistance as a wiring, take favorable ohmic contact, and function as an anode.

[0208]

In addition, the layer 616 including the luminescent material is formed by evaporation using an evaporation mask or by inkjet. The layer 616 including the luminescent material includes an organometallic complex according to the present invention. As a material to be used in combination with the organometallic complex, low molecular weight materials, middle molecular weight materials (including an oligomer and a dendrimer) or polymer materials may be used. In addition, as a material to be used for the layer including the luminescent material, it is often the case that an organic material is used for a single layer or a laminate. However, the present invention includes a structure in which an inorganic compound is used for a part of a film including an organic compound.

[0209]

Further, as a material to be used for the second electrode (cathode) 617 formed on the layer 616 including the luminescent material, a material that has a small work function, for example, Al, Ag, Li, or Ca, an alloy thereof such as Mg:Ag, Mg:In, Al:Li, or a metal compound such as  $\text{CaF}_2$  or  $\text{CaN}$ , may be used. In the case where light generated in the layer 616 including the luminescent material passes through the second electrode 617, it is preferable to use a laminate of a metal thin film that has a thinned film thickness and a transparent conductive film (for example, an alloy of indium oxide and tin oxide (ITO), an alloy of indium oxide and zinc oxide ( $\text{In}_2\text{O}_3\text{-ZnO}$ ), or zinc oxide (ZnO)) as the second electrode (cathode) 617.

[0210]

Further, the sealing substrate 604 and the element substrate 610 are bonded with the sealing material 605 to have a structure where a light-emitting element 618 is provided in the space 607 surrounded by the element substrate 601, the sealing substrate 604, and the sealing material 605. The space 607 also includes a structure of filling with the sealing material 605 in addition to a case of filling with an inert gas (for example, nitrogen, argon, or the like).

[0211]

It is to be noted that it is preferable to use an epoxy resin for the sealing material 605. In addition, these materials are desirably a material that hardly allows permeation of moisture or oxygen. Further, as a material to be used for the sealing substrate 604, a plastic substrate composed of FRP (Fiberglass-Reinforced Plastics), PVF (polyvinylfluoride), Mylar, polyester, acrylic, or the like can be used besides a glass substrate and a quartz substrate.

[0212]

As described above, a light-emitting device that has a light-emitting element according to the present invention can be obtained. In the above-described light-emitting device according to the present invention, the light-emitting element according to the present invention is excellent in emission efficiency, and can be driven for a long time. Therefore, the light-emitting device has a long lifetime with low power consumption.

[0213]



«Embodiment 5»

In Embodiment 5, various electric devices completed by using a light-emitting device that has a light-emitting element according to the present invention will be described. Since a light-emitting device according to the present invention has a long  
5 lifetime with low power consumption, an electric device using the light-emitting device can be also used for a long time by reducing, for example, power for a display portion and a lighting portion.

[0214]

Electric devices manufactured by using a light-emitting device formed  
10 according to the present invention include a television, a video camera, a digital camera, a goggle-type display (head mount display), a navigation system, a sound reproduction device (such as an in-car audio system or an audio set), a laptop personal computer, a game machine, a personal digital assistance (such as a mobile computer, a cellular phone, a portable game machine, or an electronic book), an image reproduction device  
15 equipped with a recording medium [specifically, a device equipped with a display device, which can reproduce a recording medium such as a digital versatile disc (DVD) and display the image], and a lighting apparatus. Some specific examples of the electric devices will be described with reference to FIG. 15. The electric devices using a light-emitting device according to the present invention are not limited to these  
20 exemplified specific examples.

[0215]

FIG. 15(A) is a display device, which includes a frame body 1001, a support 1002, a display portion 1003, a speaker portion 1004, a video input terminal 1005, and the like. A light-emitting device formed according to the present invention is used for  
25 the display portion 1003 to manufacture the display device. The display device includes all devices for displaying information such as for a personal computer, for receiving TV broad casting, and for displaying an advertisement.

[0216]

FIG. 15(B) is a laptop personal computer, which includes a main body 1201, a  
30 frame body 1202, a display portion 1203, a keyboard 1204, an external connection port 1205, and pointing mouse 1206. A light-emitting device that has a light-emitting element according to the present invention is used for the display portion 1203 to

manufacture the laptop computer.

[0217]

FIG. 15(C) is a video camera, which includes a main body 1301, a display portion 1302, a frame body 1303, an external connection port 1304, a remote-control receiving portion 1305, an image receiving portion 1306, a battery 1307, a voice input portion 1308, operation keys 1309, and an eye piece 1310. A light-emitting device that has a light-emitting element according to the present invention is used for the display portion 1302 to manufacture the video camera.

[0218]

FIG. 15(D) is a desk lighting apparatus, which includes a lighting portion 1401, a shade 1402, a variable arm 1403, a support 1404, a pedestal 1405, and a power source 1406. A light-emitting device formed by using a light-emitting element according to the present invention is used for the lighting portion 1900 to manufacture the desk lighting apparatus. It is to be noted that the lighting apparatus includes a lighting apparatus to be fixed to the ceiling and a wall-hung lighting apparatus.

[0219]

FIG. 15(E) is a cellular phone (device), which includes a main body 1501, a frame body 1502, a display portion 1503, a voice input portion 1504, a voice output portion 1505, an operation key 1506, an external connection port 1507, an antenna 1508, and the like. A light-emitting device that has a light-emitting element according to the present invention is used for the display portion 1503 to manufacture the cellular phone.

[0220]

As described above, an electric device that has a light-emitting element and a light-emitting device according to the present invention can be obtained. In addition, in the above-described electric devices according to the present invention, the light-emitting element according to the present invention is excellent in emission efficiency, and can be driven for a long time. Therefore, the electric devices can be driven for a long time with low power consumption, which is economical.

[0221]

30 «Embodiment 6»

In the present embodiment, a case of using a luminescent material according to the present invention and another luminescent material to form a white light-emitting

element will be described.

[0222]

In order to form a white light-emitting element with the use of a luminescent material according to the present invention, it is necessary to provide a plurality of light-emitting regions between a first electrode and second electrode and control the luminescent color from each light-emitting region so as to obtain white light as a whole. However, when a light-emitting region including a luminescent material according to the present invention, that is, a red or reddish phosphorescent material, is formed so as to come in contact with another luminescent material, energy transfer occurs between the luminescent materials, and there is a possibility that a phenomenon occurs, where the phenomenon is that light is emitted more strongly as for only the luminescent color of either one luminescent material while light is emitted more weakly as for the luminescent color of the other luminescent material. In order to improve this imbalance of the luminescent colors, a separation layer may be provided between the light-emitting regions. The separation layer is required to have a light-transmitting property, and may be formed by using an electron transporting material or a hole transporting material. Specifically, the electron transporting materials and hole transporting materials mentioned in the embodiment modes may be used.

[0223]

Next, FIG. 16 shows one example of the structure of a white light-emitting element in the case of providing two light-emitting regions. In FIG. 16, there are a first light-emitting region 2002 and a second light-emitting region 2004 between a first electrode 2001 and a second electrode 2005, and there is a separation layer 2003 between the first light-emitting region 2002 and the second light-emitting region 2004. When a blue-green luminescent material is used for the first light-emitting region 2002 and a phosphorescent material according to the present invention is used for the second light-emitting region 2004, white light can be obtained as a whole.

[0224]

As the blue-green luminescent material for forming the second light-emitting region 2002, fluorescent materials such as perylene, 2,5,8,11-tetra-tert-butylperylene (abbreviation: TBP), 4,4'-bis[2-diphenylvinyl]biphenyl (DPVBi), 4,4'-bis[2-(N-ethylcarbazole-3-yl)vinyl]biphenyl (abbreviation: BCzVBi),

bis(2-methyl-8-quinolinolato)-4-phenylphenolato-aluminum (abbreviation: BAlq), and bis(2-methyl-8-quinolinolato)-chlorogallium (abbreviation: Gamq2Cl), and phosphorescent materials such as bis[2-(3,5-bis(trifluoromethyl)phenyl)pyridinato-N,C2']iridium(III) picolinate (abbreviation: Ir(CF3ppy)2(pic)), bis[2-(4,6-difluorophenyl)pyridinato-N,C2']iridium(III) acetylacetonate (abbreviation: FIr(acac)), and bis[2-(4,6-difluorophenyl)pyridinato-N,C2']iridium(III) picolinate (abbreviation: FIr(pic)) can be given.

[0225]

10 A specific structure of FIG. 16 will be described. On a substrate 2000, ITO to serve as the first electrode 2001 is deposited so as to be 110 nm in film thickness.

[0226]

Next, the first light-emitting region 2002 is formed. Specifically, DNTPD that is a hole injecting material and  $\alpha$ -NPD that is a hole transporting material are deposited to be 50 nm and 30 nm, respectively. After that, Ir(Fdpq)2(acac) that is a red or reddish phosphorescent material according to the present invention and A-NPD are deposited by co-evaporation to be 30 nm in film thickness so that Ir(Fdpq)2(acac) is included at 8 weight%.

[0227]

20 Next, CBP is deposited to be 5 nm in film thickness as the separation layer 2003. After that, the second light-emitting region 2004 is formed. Specifically, Ir(CF3ppy)2(pic) that is a blue-green phosphorescent material and CBP are deposited to be 25 nm in film thickness so that Ir(CF3ppy)2(pic) is included at 8 weight%. Then, BCP that is a hole blocking material (and an electron transporting material) is deposited to be 10 nm, and further, Alq is deposited to be 20 nm as an electron transporting layer. After that, calcium fluoride (abbreviation: CaF2) is deposited to be 1 nm in film thickness as an electron injecting layer.

[0228]

After that, Al is deposited so as to be 150 nm as the second electrode 2005.

30 [0229]

In accordance with this process, a white light-emitting element using a

phosphorescent material according to the present invention and a blue-green phosphorescent material is obtained. In the structure of FIG. 16, a bipolar material is used for the separation layer 2003. However, a hole transporting material, an electron transporting material, a hole blocking material, or the like may be used without  
5 limitation to the bipolar material. In addition, although an example of providing two light-emitting regions is shown in the present embodiment, more light-emitting regions may be provided in order to obtain white light as a whole.

[0230]

Alternatively, in the case of using a blue-green fluorescent material to form a  
10 white light-emitting element, ITO is deposited to be 110 nm as the first electrode 2001, DNTPD that is a hole injecting material and  $\alpha$ -NPD that is a hole transporting material are deposited to be 50 nm and 30 nm respectively, and for the first light-emitting region 2002, Ir(Fdpq)<sub>2</sub>(acac) that is a red or reddish phosphorescent material according to the present invention and A-NPD are deposited by co-evaporation to be 30 nm in film  
15 thickness so that Ir(Fdpq)<sub>2</sub>(acac) is included at 8 weight%. After that, CBP is deposited to be 5 nm in film thickness as the separation layer 2003, and for the second light-emitting region 2004, perylene that is a blue-green fluorescent material and BA1q are deposited to be 25 nm in film thickness so that perylene is included at 1 weight%. Then, Alq is deposited to be 30 nm as an electron transporting layer. After that, CaF2  
20 is deposited to be 1 nm as an electron injecting layer, and finally, Al is deposited to be 150 nm as the second electrode 2005. In accordance with this process, a white light-emitting element using a red or reddish phosphorescent material and a blue-green fluorescent material can be obtained.

[0231]

25 «Embodiment 7»

In the present embodiment, the structure of a white light-emitting element using a phosphorescent material according to the present invention, which is different from the structure in Embodiment 6, will be described with reference to FIG. 17.

[0232]

30 In FIG. 17, there are a first light-emitting region 3002, a second light-emitting region 3004, and a third light-emitting region 3006 between a first electrode 3001 and a

second electrode 3007. Further, there is a carrier generation layer 3003 between the first light-emitting region 3002 and the second light-emitting region 3004, and there is a carrier generation layer 3005 between the second light-emitting region 3004 and the third light-emitting region 3006. When a phosphorescent material according to the present invention, a blue or bluish luminescent material, and a green or greenish luminescent material are used for the first light-emitting region 2002, the second light-emitting region 2004, and the third light-emitting region, white light can be obtained as a whole.

[0233]

As the blue or bluish luminescent material, fluorescent materials such as perylene, 2,5,8,11-tetra-tert-butylperylene (abbreviation: TBP), 1,1,4,4-tetraphenyl-1,3-butadiene (abbreviation: TPB), 9,9'-bianthryl (abbreviation: BiAnt), 9,10-diphenylanthracene (abbreviation: DPA), 9,10-di(2-naphthyl)anthracene (abbreviation: DNA), 9,10-di(2-naphthyl)-2-tert-butylanthracene (abbreviation: t-BuDNA), and phosphorescent materials such as bis[2-(4,6-difluorophenyl)pyridinato-N,C2']iridium(III)tetrakis(1-pyrazolyl)borate (abbreviation: FIr6) can be given.

[0234]

As the green or greenish luminescent material, fluorescent materials such as coumarin 6, coumarin 545T, 9,10-dimethylquinacridone (abbreviation: DMQd), 5,12-diphenyltetracene (abbreviation: DPT), and tris(8-quinolinolato)aluminum, and phosphorescent materials such as tris(2-phenylpyridinato-N,C2')iridium (abbreviation: Ir(ppy)3), bis(2-phenylpyridinato-N,C2')iridium(III)acetylacetonate (abbreviation: Ir(ppy)2(acac)), and bis[2-(4-methylphenyl)pyridinato-N,C2']iridium(III)acetylacetonate (abbreviation: Ir(tpy)2(acac)) can be given.

[0235]

In addition, a transparent conductive film can be used for the carrier generation layer. Specifically, an indium tin oxide (abbreviation: ITO), an indium tin oxide containing silicon, and an indium oxide including zinc oxide at 2 ~ 20 % can be given.

[0236]

A specific structure of FIG. 17 will be described. On a substrate 3000, an ITO

to serve as the first electrode is deposited to be 110 nm in film thickness, and then the first light-emitting region 3002 is formed. Specifically, as a hole injecting material,  $\alpha$ -NPD and molybdenum oxide are deposited by co-evaporation to be 50 nm in film thickness so that the mass ratio is 1 : 0.25, and  $\alpha$ -NPD that is a hole transporting material is deposited to be 10 nm. Next, as the first light-emitting region 3002, Ir(Fdpq)<sub>2</sub>(acac) that is a red or reddish phosphorescent material according to the present invention and Alq are deposited by co-evaporation to be 37.5 nm in film thickness so that Ir(Fdpq)<sub>2</sub>(acac) is included at 8 weight%. Alq<sub>3</sub> is deposited to be 27.5 nm as an electron transporting material, and as an electron injecting material, BCP and Li are deposited by co-evaporation to be 10 nm in film thickness so that the mass ratio is 1 : 0.005. Then, ITO is deposited to be 20 nm in film thickness as the transparent conductive film 3003.

[0237]

On the transparent conductive film 3003, the second light-emitting region 3004 is formed. Specifically, as a hole injecting layer,  $\alpha$ -NPD and molybdenum oxide are deposited by co-evaporation to be 50 nm in film thickness so that the mass ratio is 1 : 0.25, and  $\alpha$ -NPD that is a hole transporting material is deposited to be 10 nm. Then, as a green or greenish luminescent material for the second light-emitting region, coumarin 6 and Alq are deposited by co-evaporation to be 37.5 nm in film thickness. Then, Alq is deposited to be 27.5 nm as an electron transporting layer, and as an electron injecting layer, BCP and Li are deposited by co-evaporation to be 10 nm in film thickness so that the mass ratio is 1 : 0.005. Then, ITO is deposited to be 20 nm in film thickness as the transparent conductive film 3003.

[0238]

On the transparent conductive film 3005, the third light-emitting region 3006 is formed in a similar way. Specifically, as a hole injecting layer,  $\alpha$ -NPD and molybdenum oxide are deposited by co-evaporation to be 50 nm in film thickness so that the mass ratio is 1 : 0.25, and  $\alpha$ -NPD that is a hole transporting material is deposited to be 10 nm. Then, as a blue or bluish luminescent material for the second light-emitting region, t-BuDNA is deposited to be 37.5 nm in film thickness. Then, Alq is deposited to be 27.5 nm as an electron transporting layer, and as an electron

injecting material, BCP and Li are deposited by co-evaporation to be 10 nm in film thickness so that the mass ratio is 1 : 0.005. Then, as the second electrode 3007, aluminum is deposited to be 200 nm in film thickness. In this way, a white light-emitting element into which the red or reddish phosphorescent material according to the present invention is introduced can be obtained.

[0239]

Although an example of providing three light-emitting regions is shown in the present embodiment, two light-emitting regions, or four or more light-emitting regions may be provided in order to obtain white light as a whole.

10 [Brief Description of the Drawings]

[0240]

[FIG. 1] A view illustrating a structure of a light-emitting element according to the present invention.

[FIG. 2] A view illustrating a structure of a light-emitting element according to the present invention.

15

[FIG. 3] A view illustrating a light-emitting device.

[FIG. 4] A diagram showing an absorption spectrum and an emission spectrum of an organometallic complex obtained in Synthesis Example 1.

[FIG. 5] A diagram showing an absorption spectrum and an emission spectrum of an organometallic complex obtained in Synthesis Example 2.

20

[FIG. 6] A diagram showing an absorption spectrum and an emission spectrum of an organometallic complex obtained in Synthesis Example 3.

[FIG. 7] A diagram showing an absorption spectrum and an emission spectrum of an organometallic complex obtained in Synthesis Example 4.

[FIG. 8] A diagram showing an absorption spectrum and an emission spectrum of an organometallic complex obtained in Synthesis Example 5.

25

[FIG. 9] A view illustrating a structure of a light-emitting element in Embodiment 1 and a manufacturing method thereof.

[FIG. 10] Diagrams showing initial characteristics of the light-emitting element manufactured in Embodiment 1.

30

[FIG. 11] A view illustrating a structure of a light-emitting element that uses a host material in Embodiment 2 and a manufacturing method thereof.



[FIG. 12] Diagrams showing initial characteristics of the light-emitting element manufactured in Embodiment 2.

[FIG. 13] Diagrams showing initial characteristics of the light-emitting element manufactured in Embodiment 3.

5 [FIG. 14] Views illustrating a light-emitting device that has a light-emitting element according to the present invention in a pixel portion.

[FIG. 15] Views illustrating specific examples of electric devices to which the present invention is applied.

[FIG. 16] A view illustrating a structure of a light-emitting element in Embodiment 6  
10 and a manufacturing method thereof.

[FIG. 17] A view illustrating a structure of a light-emitting element in Embodiment 7 and a manufacturing method thereof.

[Reference Numerals]

[0241]

15 100 substrate  
101 first electrode  
102 layer including a luminescent material  
103 second electrode  
111 hole injecting layer  
20 112 hole transporting layer  
113 light-emitting layer  
114 hole blocking layer  
115 electron transporting layer  
200 substrate  
25 201 first electrode  
202 layer including a luminescent material  
203 second electrode  
211 electron transporting layer  
212 hole blocking layer  
30 213 light-emitting layer  
214 hole transporting layer  
215 hole injecting layer

300 substrate  
 311, 312 TFTs  
 313 light-emitting element  
 314 first electrode  
 5 315 layer including a luminescent material  
 316 second electrode  
 317 wiring  
 400, 500 substrate  
 401, 501 first electrode (anode)  
 10 402, 502 layer including a luminescent material  
 403, 503 second electrode (cathode)  
 411, 511 hole injecting layer  
 412, 512 hole transporting layer  
 413, 513 light-emitting layer  
 15 414, 514 electron transporting layer  
 415, 515 electron injecting layer  
 601 driver circuit portion (source side driver circuit)  
 602 pixel portion  
 603 driver circuit portion (gate side driver circuit)  
 20 604 sealing substrate  
 605 sealing material  
 607 inside surrounded by the sealing material 605  
 608 wiring  
 610 substrate  
 25 611 switching TFT  
 612 current controlling TFT  
 613 first electrode  
 614 insulator  
 616 layer including a luminescent material  
 30 617 second electrode  
 618 light-emitting element  
 623 n-channel TFT

624 p-channel TFT  
 709 FPC (Flexible Printed Circuit) that serves as an external input terminal  
 1001 frame body  
 1002 support  
 5 1003 display portion  
 1004 speaker portion  
 1005 video input terminal  
 1201 main body  
 1202 frame body  
 10 1203 display portion  
 1204 keyboard  
 1205 external connection port  
 1206 pointing mouse  
 1301 main body of a video camera  
 15 1302 display portion  
 1303 frame body  
 1304 external connection port  
 1305 remote-control receiving portion  
 1306 image receiving portion  
 20 1307 battery  
 1308 voice input portion  
 1309 operation keys  
 1310 eye piece  
 1401 lighting portion of a desk lighting apparatus  
 25 1402 shade  
 1403 variable arm  
 1404 support  
 1405 pedestal  
 1406 power source  
 30 1501 main body of a cellular phone  
 1502 frame body  
 1503 display portion

	1504	voice input portion
	1505	voice output portion
	1506	operation key
	1507	external connection port
5	1508	antenna
	2000	substrate
	2001	first electrode
	2002	first light-emitting region
	2003	separation layer
10	2004	second light-emitting region
	2005	second electrode
	3000	substrate
	3001	first electrode
	3002	first light-emitting region
15	3003	carrier generation layer
	3004	second light-emitting region
	3005	carrier generation layer
	3006	third light-emitting region
	3007	second electrode

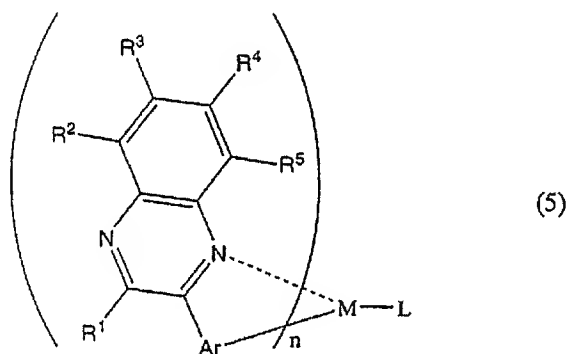
[Document Name] Abstract

[Summary]

[Problem] To obtain a light-emitting element that can be driven for a long time, is high in emission efficiency, and has a favorable long lifetime, and a light-emitting device using the light-emitting element.

[Solving Means] A light-emitting element that has a pair of electrodes which are an anode and a cathode and a light-emitting layer between the pair of electrodes, where the light-emitting layer includes an organometallic complex represented by the following general formula (5) and one of a compound that has a larger energy gap than the organometallic complex and a compound that has a larger ionization potential and a smaller electron affinity than the organometallic complex, and a light-emitting device using the light-emitting element.

[Chemical Formula 5]



15 [Selected Drawing] FIG. 1